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IRRIGATION WORK
IN INDIA.
VOLUME II.—APPENDICES.

BY

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ALLAHABAD:
PRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS, UNITED PROVINCES.
1919

On sale in the Book Depot, Thomason College, Roorkee.

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APPENDIX I.

MAPS AND SURVEYS.

The following Maps and Surveys should be prepared and submitted with the Project.

1 **Index Chart.**—Scale about 16 miles to the inch or in the case of very large Projects, 32 miles to the inch (*Plate* I) This map is required to show the geographical position of the canals, distributaries, main works, and existing or proposed works of communication, which can be marked by thick lines of distinctive colours on a part of any general published map of the country. The Index Chart should face the title page of the Report, and should be cut and folded accordingly. It is frequently desirable to put up a tracing instead of the printed map, omitting unnecessary printed details, and showing more clearly the course and position of rivers, and other topographical features affecting the engineering of the work.

2. **Well Water Chart**—Scale 16 miles to the inch (*Plate* II). On this map, the outline of which can be traced from the Index Chart, should be shown, by distinctive colours, the areas debarred and irrigable, and by contours, the levels of the surface of the subsoil water—this information should be reduced from the large scale maps described further on. The distribution of well irrigation is best shown graphically on the Well Irrigation Map by taking the percentages of culturable area actually irrigated in the year in the villages, and grouping the results under distinctive colours; thus 0·0 may be coloured burnt sienna, 0 to 10 light yellow, 10 to 20 light red, 20 to 30 green, 30 to 40 cobalt, and so on; the areas which it is determined to debar from canal irrigation as being already sufficiently provided for by wells or other sources being coloured carmine The subsoil water contours should be spaced for every 5 feet of variation in level. Besides the above technical information, only the alignment of channels, rivers, railways, main roads and large towns need be shown on this map, which should be bound up with the report.

3. **General Map.**—Scale 4 miles to the inch. In India the Atlas sheets published by the Survey of India may be used as the foundation for this map, on which can be shown in considerable detail the existing and proposed railways and roads, the general alignment of all channels, and the position of all works, which latter should be denoted by red block numbers, referable to a list to be included in the report. The

Atlas sheets should be traced on one continuous roll, omitting all but towns and important village names, and showing clearly by broad dotted lines the district and pargana boundaries; and by colour, the course of the rivers, main drainage lines and other topographical features. The direction of flow of water should be marked by arrows, and the names of rivers and streams given.

The boundaries of the collecting basins of each natural drainage line should be demarcated on this map by broad coloured lines, and the areas in square miles, and calculated discharges in cusecs, printed on in large block green figures. The discharge of each irrigation channel should be printed opposite the head, in a similar manner in somewhat smaller block blue figures. As the printed Atlas sheets show little besides works of communication, inhabited sites, rivers, main streams and hills, it is evident that considerable detail from surveys and other sources will have to be added to compile this map.

4. **Level Chart.**—Scale 2 mile to the inch (*Plate* III). The Great Trigonometrical Survey of India have published a series of charts on this scale, each chart including 30 minutes of latitude and one degree of longitude, i.e., about $34\frac{1}{2}$ by 61 miles; and have shown on them all the reliable levels they could procure, with bench-marks, all levels being reduced to the same datum, i e., the mean sea level of the sea at Karachi. To each chart is attached a book containing the descriptions of the bench-marks shown on the chart. The series is not complete, nor are the charts up to date, but the Survey office publish new, and revise published charts, as fast as fresh information is available, and the funds placed at their disposal admit. The latest editions of these charts, comprising the area to be dealt with, should be procured, and bound into an atlas, blank prepared sheets being added in their proper places if the series is not complete. The levels taken for the project should be plotted on these charts; it will not be found necessary to enter all readings, as this would make the charts confusing, but marked variations in ground level, observations of water surface, beds of rivers, streams, etc., and bench-marks, should be shown, including an outline survey of important objects—in fact the entries should, as far as possible, correspond with the style of the printed maps. As the maps are printed in black, it will be well to show new levels in carmine, and it may here be noted, that the Survey office will gladly accept and publish the new levels if it can be satisfied as to their correctness.

These charts, however useful as a record of the operations, with a view to eventual publication, are much more necessary for circle checking of the levels. For this purpose, all lines of levels should commence and end on bench-marks, either ones previously fixed, the reduced levels of which have been determined and checked, or new bench-marks, to be picked up and checked hereafter by independent lines. If the Engineer is fortunate enough to find on the charts a number of bench-marks, so situated as to be readily available for checking on, his work will be much simplified. This however is not usual, but in most parts of India reliable bench-marks will be found, in sufficient number, to assist materially in starting work, and checking it, at intervals more or less distant; and additional bench-marks should be determined for future use at intervals averaging one mile apart The closing error in each circle should be entered on the chart, and if considered advisable, though this is a much disputed point, the values of the bench-marks can be corrected to the mean given by different observations. In no case, however, should the levels of any line be accepted for irrigation work where the difference exceeds 0·10 foot in 16 miles, nor should this difference be passed if it is accumulative. It may here be noted that the so-called circle in levelling has nothing to do with the scientific definition—it merely denotes that the level lines join one to the other, so as to enclose a space however irregular. In the diagram the letters denote bench-marks, and the dotted lines level sections; it is evident that any error made in levelling from A to C, C to D, D to F, and F to A, will be detected when closing the levels on A, and this is called the closing error—this is entered in the diagram in red as 0·07 (*see Fig.* 12, *Plate* VIII).

There may be, in fact often are, intermediate errors which sometimes compensate themselves, and these if serious, will at once be detected by the line BE, or by outside lines, joining on to the intermediate bench-mark B and E. The errors in the small circles are entered on the diagram as 0·0 and 0·10. It will now easily be seen how useful the level chart is to the Engineer, for as the Surveyors send in to headquarters the plots of their surveys, their work can be checked, and. if necessary, further check lines, to settle doubtful points, asked for, the information on the chart can be added to, and ultimate values of bench-marks determined, and entered finally. Human nature is fallible, and these charts should, during the progress of field work, be kept as far as possible in the personal custody of the Engineer, and Surveyors informed of the value of their starting bench-marks only, being directed to send in the values they make on intermediate bench-marks as they pick them up during the progress of

their work. It need hardly be said that the drawings and descriptions of all accepted bench-marks should be entered in the books attached to the maps.

For purposes of easy reference an index, scale 40 miles to the inch, should be pasted on to the cover of the atlas.

5. **Well Irrigation Map.**—Scale 1 mile to 1 inch (*Plate* IV). This map can only be prepared with accuracy and economy of districts for which agricultural records are kept up by the Revenue branches of the administration. This, however, is now very commonly the case throughout India to owing the improved system of statistical account introduced by the Department of Land Records and Agriculture ; and it may with truth be said that for no other part of the world can more accurate agricultural statistics be produced. The field entries are made by the Patwaris or village accountants during their periodical tours--that for the *kharif* or rain harvest commencing on or after the 15th August , for the *rabi* or cold weather harvest commencing not earlier than the 1st January—and the third tour which is required to record crops sown after the *rabi*, but before the *kharif*, commencing about the 15th or 30th April. The patwari's circle or beat comprises one or more villages, but the area does not usually exceed 1,500 acres , the work of the Patwari is checked by a superior official called the Supervisor Kanungo. The patwari on his tours enters during the year, in the *Kasra*, the circumstances of every field, including its area, crop, method of irrigation if any, owner, cultivator, and class of soil, etc. Many of the annual entries when unchanged, can be copied from the Settlement records, but corrections, if found necessary, are shown in the *Kasra ;* from the *Kasra* are compiled abstracts for the year, showing the totals of each class of soil, crop, irrigation, etc. The abstract, which most particularly concerns the Canal Engineer, is called the *milan Kasra*, and from it can be obtained, in addition to other information, the actual area irrigated by wells, and the total culturable in each village during any selected year. Besides wells, and canals, there are in India other sources of irrigation, such as direct lift from small streams and tanks ; but these sources may, as a rule, be rejected from the calculations of permanent existing irrigation, as they are liable to fail in years of scanty rainfall. It is true that the supply from some wells is liable to fail also, but for the preliminary determination of canal irrigable and debarred tracts, the actual areas irrigated from wells in a moderately dry year may be accepted with confidence. In order to show graphically the extent and distribution of the well irrigation over a large area, it is convenient to

calculate the percentage of culturable area irrigated in each village, and to enter this, in clear figures, on a map of a scale large enough to show village boundaries. The 1 mile to the inch Revenue Survey Maps are the best possible for the purpose, but the series is not yet nearly complete even for Northern India. These maps comprise an area of 15 minutes latitude by 30 minutes longitude, or about 17¼ by 30½ miles and the set covering the area of the project should be traced on one sheet, showing only the following; viz. boundaries, names of territorial divisions, main existing communications and rivers. The alignments of the proposed canals should be shown by broad carmine lines If the ground work of the map is at all confused, great trouble and inconvenience will be found to attend the process of entering correctly the percentages, and as the same village name frequently re-appears in different places, indeed sometimes in the same pargana, the search for a particular village on a large map often takes more time and trouble than would at first be thought possible. It will be well, therefore, to fix a number to each name in the Agricultural Register, and have this clearly entered on the map in black, instead of the name, before entering the percentages in red figures. If this number of the village is kept as a register number throughout all the records of the project in which the village is referred to, much time and trouble will be saved. If published maps are not available as a 1 mile to the inch map, showing village boundaries, they must be prepared from any other available source.

The foundation for the map having been prepared, and the register and percentage number entered, it may be coloured, village by village, as explained for the Well Water Chart (*see* paragraph 2) according to the percentages. It will usually be found that the extent of irrigation will be nearly the same in a large number of adjoining villages, and this will, in well-populated tracts, correspond very fairly with the natural facilities for well irrigation. The Indian cultivator is much more awake to his own interests than is commonly supposed, and rarely leaves his opportunities of this nature unavailed of when it is economically possible to use them.

It need hardly be said that the early preparation of this map should be considered as of the first importance, as the positions of the alignments will, to a great extent, depend on the information given by it.

6. Subsoil Water Map.—Scale 1 mile to 1 inch (*Plate* V). This map is intended to show the contour of the surface of the water in the subsoil in the same manner as the Professional Map (*see* paragraph 7) shows the contour of the surface of the ground. It is not necessary for the

preparation of the project, but will be found valuable after the canal has been opened and irrigation has progressed for some time To prepare it a tracing should be made of the Wells Irrigation Map, omitting the percentages and their colours, and on this the reduced levels, as observed, of the surfaces of the water in well should be shown, and the contours drawn at suitable intervals. In t acts with a slight transverse slope the interval may be taken at one foot of level without confusion, but every fifth foot should be distinguished by a thick line ; the contours look best if laid on in Indian ink with a fine brush. It is also advantageous to show large areas of marsh or lakes on this map by a blue wash. The water surface levels and position of marsh lands can be extracted from the Professional Map. It is not necessary to fix the sites of observations, and boundaries of the marshes, with extreme accuracy, a sharp draftsman will be able to sketch them in by eye near enough to serve all practical purposes. The reduced levels should be figured in cobalt to the nearest foot, omitting decimals.

The surface of water in wells *generally* falls after the close of the rains, and during the cold and hot weather. As it is obviously impossible to measure all the wells on the same day, except by special agency, which would probably not give a very accurate record, it will be well to enter the dates between which each section was levelled on the map. This can be shown on the margin, and the surface level of the supply in rivers and streams should also be shown with the dates of each observation. If the project does not command the full area of the *doab* up to the bounding rivers on either side, it will be necessary to take special sections at intervals not exceeding 5 miles, extending to the nearest rivers, without these the transverse slope of the subsoil water would remain undetermined, which would deprive the observations of a great part of their value. After the canal has been opened these sections will form the ground work of a series of monthly or weekly observations which it is always found necessary to take to determine the rise in the subsoil water surface due to percolation of water from the canal. Subsoil water sections should be taken as nearly as possible at right angles to the courses of the main streams, the level sections following the same lines are therefore well adapted for both systems of observation.

7. **Professional Map** —The Professional or Engineering Map is the working plan for the Project (*Plate* VI). It is used for laying out all lines and engineering arrangements, except special details of very large works, which are usually shown on what are called Site Plans (*see*

paragraph 8). It is evident that the Professional Map, to fulfil its pur-poses in a satisfactory manner, should contain sufficient and accurate information of the contours, soils, drainage and other necessary details of the ground surface, and that it should be prepared on a scale large enough to show these details clearly.

The scale usually adopted when the survey has to be made *ab-origine*, is 4 inches to the mile: when the project deals with well-cultivated and settled tracts, the best scale to use is that on which the village maps are printed, generally 16 inches to the mile.

The procedure to be adopted for the preparation of this, the most important map of the project, will differ materially for unsettled sparsely populated tracts and highly cultivated settled country. In the first case an original survey of the whole tract will generally be necessary, and in the second, it will nearly always be possible to make an economical and valuable use of existing maps

Maps made by original survey.—Dealing with the first case, when an original survey is required, it can be carried out according to the usual rules for surveying, but the following scheme of operations will generally be found useful.

The trigonometrical observations may be confined to the fixation of stations fairly evenly distributed over the whole area, these stations being used to check the accuracy of the various compass traverse lines. The levelling operations will consist of a base line running down the centre of the *doab* as near as may be, very carefully levelled and *checked*, and including permanent bench-marks at the intervals selected for cross sections. The cross sections to be connected as circles with the base line bench-marks and to be run at right angles to the general direction of the bounding rivers. All these level lines to be traversed with the compass, and a careful survey to be made along the lines themselves, and as far on each side as can be conveniently measured with the offset rod. (*See Fig.* 13, *Plate* VIII.)

The detail survey between the cross section lines to be filled in with the prismatic compass and plane-table, careful attention being paid to the direction of the flow of drainage in the most apparently insignificant as well as important cases. This should never be overlooked, and copious notes should also be taken of water levels in ponds and streams, of the discharges of the latter, and of the existence of materials of construction—all these notes can be eventually shown on the map in conventional terms.

When surveying in details it will be well to adopt a systematic plan, and to instruct all Sub-Surveyors accordingly, otherwise time will be wasted and opportunities lost in recording items of no interest, while probably important features may be overlooked or omitted altogether. As far as regards drainage, which is the most important item in an irrigation survey, it is best to follow up each drainage line from below, taking up and completing each branch line with its gathering ground as its junction with the main is met with. When this has been done thoroughly, it will be found very simple work putting in the rest of the important detail, such as isolated swamps, ponds, village sites, roads and groves.

When it is practicable the main drainage lines should be levelled at the same time they are surveyed, this can be done by using the same spirit level with compass which was used for cross section work. The advantages of having these drainage levels are very great—they are useful for the engineering of the line, make the contours to be afterwards put on a really valuable guide to the surface of the ground, and afford strong indications of the true lie of the watersheds.

Some Engineers consider it very desirable to demarcate the areas of land flooded during the wet season. No doubt this information is useful, but it is somewhat expensive to record: it can be done, if considered necessary, by making careful local enquiries, and traversing the areas said to be flooded with the prismatic compass.

It will be necessary to show the boundaries of the lands of existing villages on the Professional Map made by original survey, but if settled villages exist to a large extent, the procedure hereafter described for this class of country should be followed instead of making a special survey: and where the country is unsettled, the Revenue authorities will, of course, determine the method by which the land, after it has been provided with irrigation, will be divided among proprietors and cultivators. As there are many advantages in distribution of water in making such boundaries agree with the drainage lines, it is probable some such system will be followed, and the Professional Map itself used for the purpose of fixing them—this has been done on the newly-settled irrigation tracts in the Punjab with great success.

Contours—After the levels and survey have been plotted, the contours can be drawn: these require great care, and that good knowledge of the general lie of the country which will have been acquired by the Engineer during his field surveys and inspections. The arrows ⟶ marking the flow of drainage and the surveys of catchment areas, will

afford the greatest assistance, and quite prevent serious errors being made. Contours are best shown in plain Indian ink lines laid on with a fine brush, the lines being about $\frac{1}{24}$th of an inch thick. For the flat country usually traversed by canals in India they may be spaced apart at one foot intervals for height. It is advantageous to make, say, every 5th or 10th contour $\frac{1}{12}$th of an inch thick

Preparation of the Professional Map.—As the Professional Map has to be worked on a great deal, the best cloth-mounted paper should be used. This can be had in wide rolls (generally 52 inches) of any length or in sheets. The paper should be ruled with fine black lines 4 inches apart in squares, running North and South, East and West, each square thus contains one mile of area. These lines will serve to check the plotting of distances, to determine areas, and act as meridians for plotting bearings with the circular protractor.

For large projects it will be found convenient to plot each major *doab* on a separate roll in preference to plotting the whole area on separate sheets. For small projects either one roll or a number of separate sheets can be used according to the width of the country.

When long rolls of paper are used it will be found very convenient to have a special table fitted with end rollers for this map The details of the table will be easily understood from the sketch, *Fig* 14, *Plate* VIII. The portion of the map not actually in use being rolled up preserves it from dirt and injury.

The cross section lines as they are taken should be plotted permanently on the map by fine carmine lines, staff stations being shown by a slight projection thus |______|______| opposite which the reduced levels should be entered in fine black figures. Only *the Register numbers* of bench-marks ought to be shown on this map, the value determined being recorded in a register in the personal custody of a responsible officer.

The details surveyed can be plotted on this map as the information is collected, and coloured up as each portion is completed according to the authorized system, care being taken that undue prominence is not given to any feature.

It is a moot point as to whether Surveyors should be allowed to come to headquarters to plot their surveys directly on the map, or whether they should plot them in the field on separate sheets, and send the sheets to be transferred to the map. Although there are advantages in having surveyors to headquarters at times, the separate plot is the most economical system, and the map gains, in so much as being all prepared by

trained Draftsmen—the workmanship will be better, and technical signs, etc., uniform.

The boundaries of villages should be shown with a distinct black line, as the village will be a unit in the water-distribution system. Trijunction and other boundary pillars should be marked on, and either names or numbers of the villages entered clearly.

Alignments—When the contours are completed the map will be suitable for determining the trial alignments, which will of course be shown in pencil only, until finally laid out, when they can be made permanent in carmine lines, $\frac{1}{8}$th inch thick for major and $\frac{1}{12}$th inch for minor lines. Miles may be numbered in carmine enclosed in a circle of the same colour, half an inch diameter, the levels of the permanent line bench-marks at 1,000 feet intervals being shown in red figures. If there are any marked changes of level between each bench-mark, the intermediate level showing this may be also entered in black, but as a general rule, the intermediate readings at 100 feet intervals are not required for this map. After the permanent lines have been entered, any needful corrections in the contours can be made by rubbing out the contour lines where they cross the permanent lines, and re-drawing them in the proper position, such corrections will, however, be seldom required, if the contours are laid down with care in the first instance. The information shown on this map will be quite sufficient to allow of the lines of the village water-course being indicated on it, these lines can in the future be laid down with accuracy after careful local enquiry Their indications will be useful, however, as it will give the point of take off the major or minor Government line, and will thus allow of a proper calculation of dimension of channel for the supply of water.

The discharge of each water-course will have to be calculated according to the rules for distribution laid down for the guidance of the projector, on the irrigable area of culturable land commanded by the water-course in question. This area can be determined from the Professional Map if it has been properly prepared.

Professional Map for settled tracts—In India and countries where Village or Estate maps exist, the preparation of the Irrigation Engineering Map can be carried out with great economy and efficiency by using these local plans as a ground-work on which to show the professional details necessary for correct alignment and distribution of water.

The economy consists mainly in the fact that base line and cross section levelling become unnecessary, levelling operations being confined to the alignment and main drainages; and that as a general rule, the only

original survey necessary will be the local surveys along construction lines, and at the sites of large works.

The efficiency in the use of these maps results from the great accuracy and detail with which drainages, watersheds and soils can be *demarcated* in the field, debarred* areas marked off, and command and culturable areas calculated

The general scheme (described in detail below) of utilizing Village or Estate maps is to trace each village separately on thin white cloth for use in the field, and to make a second trace also on cloth combined in separate *doabs* for use in the office. The observer prepares the maps in the field according to the instructions given to him, and the Draftsman in office transfers this information to the general *doab* maps, and at the same time colours up the physiographical details and the soils. The plan thus prepared is then ready for marking off all alignments down to village water-courses, and the calculations of area to be irrigated and discharges of channels can be made directly from it.

The alignments should then be surveyed on the ground, laid down and levelled, when the general engineering of the project can be carried out.

In India Village maps † are usually prepared on a scale of about 16 inches to the mile, the scale has to be fairly large to show the boundaries of each field and its number. Under this number in the Settlement Record‡ is shown the owner, cultivator, area, soil and other information. It is from this record that the head office Draftsman is able to colour up the soils on the combined village *doab* map.

The village maps also show the sites of village residences, culturable and barren land, groves, tanks, and a few other features by distinguishing marks referable to an Index printed on the map.

The *doab* map is prepared for office use by colouring up the following features —inhabited sites and masonry wells, carmine, streams and tanks, cobalt, groves green, roads, light red, unmetalled being dotted only. Edges of broken ground, where clearly shown, can be shaded sepia, and barren land burnt sienna Land which is culturable, § though uncultivated, should not be coloured, only absolutely unculturable land.

The separate traces on cloth of the village maps should have the English name and register number printed on, and can then be made over to

* Certain areas are debarred from canal water when they possess good natural irrigation facilities

† Vernacular *shajra*.

‡ Vernacular *kasra*.

§ If time can be spared it is very advantageous to colour up two of the three main classes of culturable land, viz, clay, loams, and sand,

the men employed on demarcation of drainages and watersheds. Before describing the work to be carried out by these men, it is needful to draw attention to the small size of fields in India where high cultivation exists. In many places the area of fields separately assessed for revenue purposes varies from a quarter to one acre, and often over large tracts not a single field will be found exceeding two or three acres in extent. This, and the fact that the boundaries of fields were in most cases originally marked off according to local peculiarities of the ground surface, renders the village map an admirable index on which to demarcate natural topographical features. The boundaries of fields in Northern India are not marked as in England by hedges and ditches, but by a narrow strip of uncultivated land, usually 2 to 3 feet wide.

The points to which the demarcation observer's attentions should be particularly directed are—the demarcation of the edges of marshes or land liable to remain flooded for some time after the rains, of the high edges of the valleys of rivers, ravines, and drainage lines dry except during the rains, the delineation of the local flow of drainage, and all the dividing watersheds.

To carry out this work, the observer should, with the map in hand, walk over the village land identifying his position by the field numbers and marking the survey directly on the map with a red, blue and black lead pencil The first two items are easily identified, and with ordinary care errors should be few, but the true direction of flow of drainage in flat countries is frequently difficult to determine. The observer should always take one or two respectable cultivators out with him; these men from long experience know perfectly well how the rain water flows off every field in the village. From interested motives they, however, occasionally give false information, their testimony should therefore be tested as thoroughly as possible both by enquiries from a number of individuals, and by the observer's own judgment. The direction of flow should be shown on the map by arrows ⟶ in black lead pencil marks It will be well first to mark the flow into and out of all ponds and marshes, taking the line from one boundary of the village to the other, and afterwards to investigate local depressions and inhabited sites. Near these latter the natural course of the drainage is often confused by artificial tanks dug for the supply of earth for house-building. One point regarding the flow of drainage requires particular attention. when rain first falls in the wet season, the tanks and hollows being mostly dry, water flows into them from all sides, and not infrequently water will at first flow from one tank to another until the latter is full, when the

drainage will reverse its course in order to take the direction of the natural outlet from the village to some main stream. This perfectly natural travel of drainage is liable to lead to errors, unless care be taken, and the observers should be cautioned to enquire regarding the ultimate flow and outlet of the drainage, and not at once to assume that a cultivator is trying to deceive them because he at first says one thing and then the opposite. As a rule cultivators, if quietly taken, will be found very trustworthy exponents of the physiographical features of their lands

When the drainage lines small and great, and other well marked features have been shown on the village map by the observer, the dividing watersheds should be followed up and marked by dotted pencil lines. Any intelligent cultivator will show the observer points between any two drainages from which water flows in both directions to the drainages on either side, and these points being observed and connected field by field, give the exact alignments of the various watersheds As the observations proceed and village is joined to village, these watersheds will be found to follow a regular system of mains and minors, covering and commanding field by field the whole area of the tract observed.

The procedure described may appear difficult, and so it will be to the observer at first, but after a little practice he will find himself becoming quite an expert and able to follow the course of drainage almost as fast as he can walk

The maps when thus prepared and checked should be sent to head-quarters for transfer to the *doab* maps.

The well irrigation maps will have served to determine villages totally debarred from canal irrigation by reason of their already having a sufficient area provided from natural sources Now, though it is presumed that the Engineer will have made himself acquainted generally with the extent of well irrigation as early in the progress of the project as possible, and will have avoided the waste of time and money consequently on the preparation of village maps for extensive sketches of debarred villages, yet there will nevertheless, as a rule, be many villages of the class situated on the edges of, or in the midst of, moderately irrigated tracts, for which engineering details are required to elucidate the features of the irrigable country. The maps of these villages should have *debarred* printed under the title, to avoid the chance of error in calculating the distribution details in the future, and are then complete, except for the alignments which may chance to cross them.

Debarred areas.—The villages in which there is no existing well or other permanent source of irrigation are also complete so far, but villages

with low percentages of culturable area irrigated require further treatment.

It was noted in paragraph 5 that the record (*milan kasra*) from which the well irrigation map was prepared, is the abstract of the *kasras* field-to-field record. These records are destroyed when three years have elapsed from date of measurement, so care should be taken to select the *milan kasra* of a year for which the details exist. In India these *kasras* can be obtained on loan from the District Revenue officers, and from them every field which has received irrigation during the year can be marked on the map. Two persons are required to carry out this work economically--one to read from the *kasra* and one to mark the map. The *kasra* gives not only the class of irrigation, but the source from which it was derived, and as wells are recognized by the number of the field in which they are situated, the full detail can be readily shown on the map in the centre of the field, thus $\frac{\text{WR}}{215}$ would denote a field watered from the well situated in field No. 215 during the *rabi* season, and $\frac{\text{TK}}{145}$ would denote a field watered from a tank situated in field No 145 in the *kharif* season. The advantage of showing the source of the irrigation is, that it enables the Engineer to at all events make an effort to avoid cutting fields off from the wells that irrigated them when aligning his channels, though it may not always be possible to do this owing to the disposition of the ground. In order to compensate for the changes in yearly irrigated area consequent on "fallow" and rotation of crops, the actual area irrigated during three years should be shown—this is certainly the proper course to pursue if time and funds are available.

After the maps have been written up from the *kasras* the Engineer himself, or some thoroughly competent assistant, should mark the boundaries of debarred areas, surrounding them by a thick purple line. These boundaries should include the fields actually irrigated, and also any other fields which from their local situation appear commanded by the wells, even though not included in the *kasras*. It is also expedient to debar narrow or small tracts lying either between two debarred areas, or between a debarred area and a large stretch of waste land, unless these narrow strips seem likely to form convenient paths for leading channels to large isolated dry tracts. These details, or at least the boundaries of the debarred areas, should of course be transferred to the *doab* maps. It is handier in the first instance to record them on the separate village maps; moreover, a large number of men can thus be kept at work at the

same time As will be seen further on, these separate village maps will be found most useful after irrigation has commenced.

The village maps must not, however, be considered quite complete until the permanent lines of channels have been shown on them. Surveyors should be deputed for this purpose as soon as the lockspits have been dug. The lines can be fixed on the map by measuring with a 10-foot rod from the place where they cross each field boundary (vernacular *dowla*) to the nearest corner or junction point with another boundary. This measurement should be both scaled on map and entered in figures, and the bench-marks at 1,000 feet intervals should also be fixed. On return to headquarters, the reduced levels should be entered, and when water-courses are being aligned the village map should be utilized, and the exact position of the channels shown by dotted lines, which can be made continuous after the water courses have been dug

The value of these prepared village maps to the practical irrigator cannot be over-estimated, they contain on a large scale and in full detail every item of information necessary for efficient distribution, and they should be preserved as office records with great care The most practical method of dealing with the large number of maps which are required for extensive projects is to keep them in special sheet-iron record cases, wrapped round wood rollers, to which the narrow edge of the map may be fastened, and the end of the roller should bear the register number of the map. Villages vary greatly in area, and maps over the average size should be divided into two or more parts.

8. **Special maps and land plans.**—Scales various. It is not necessary to submit special Land plans with the Project, as no land can be acquired until formal sanction to the execution of the work has been obtained; and the channel alignments marked on the village maps afford all the information necessary for the most detailed estimate of cost, and will, in the future, be found valuable aids in the preparation of regular land plans. For the Project, pencil lines showing the widths required can be ruled on the village maps, to estimate the areas of waste, culturable and cultivated land.

Besides the maps described above, various special large scale maps will be required, such as enlarged plans of Head-works, Torrent crossings and alignments near large towns, etc. The particular necessity for and nature of any of them will depend on the class of project under preparation, and no further remarks regarding them are necessary, except that special surveys along alignments should not be required if the professional map is properly prepared.

FIELD WORK

9 **Base line.**—When starting the Professional Map as an actual survey, after the fixed points for the check of correct position of the prismatic compass survey lines have been determined with the theodolite in the usual manner, the first work to be put in hand in the field will be the laying out and levelling of the base line, keeping as straight as may be a course midway between the two main bounding streams. This base line should commence and end on reliable bench-marks, the levels being double checked throughout with great care.

10. **Bench-marks for cross sections**—At intervals on the base line to be determined beforehand, bench-marks for starting cross sections should be fixed, the spacing of these intervals will depend partly on the amount of existing information, and partly on the nature of the ground With the slopes usual in Northern India cross sections ought not to be more than ½ mile apart. The intervals which have been accepted in projects previously carried out, vary from 3,000 feet to 5 miles; but the increased knowledge of irrigation matters acquired by experience, and in consequence the improvements now being daily made in the system of distribution, call for a much more intimate knowledge of the ground surface contour than was formerly considered necessary; and in very complicated country cross sections may have to be taken closer even than ½ mile from each other

11. **Section Levelling.**—Without trenching on the province of works devoted to the manipulation of surveying instruments, the following simple rules for section levelling may be given as particularly applicable to Irrigation work:—

(i) The flood or high water, bed and surface water levels of all rivers, streams, tanks or wells met with, to be recorded as intermediates, and the date of record to be noted. From the water surface levels in wells, a percolation level line will be plotted on the longitudinal section, and to get this line as accurate as possible, the depth from ground surface to water surface should be noted for all wells near the line.

(ii) Except in the case of large rivers requiring special appliances, the discharges of rivers and streams met with to be measured, and recorded with date, once at least for every 5 miles of their course through the Project country.

(iii) The existence or absence of the *mota* and its distance below the ground surface and thickness, to be recorded for all wells met with.

N.B.—This information can be given by all well owners.

(iv) On section levelling the staff man to carry in a wallet a mallet and a small supply of well made round pegs 6 inches long, 1¼ inches diameter on top, which should be slightly rounded. Each staff man to drive his own peg in the spot marked for him by the chain man, and to see a deep circular lockspit, 18 inches diameter, dug round it before he leaves.

The Instrument station to be marked by a crow's foot Y in the same manner. The staff man to remain at his station until both the fore and back sights have been read; a large numbered peg, 18 inches long by 3 inches square at top to be fixed instead of the small peg at all important angles of the section line, and at the completion of each day's work as the last peg.

(v) As far as is consistent with the acquirement of a true record of the ground surface, stations to be kept at even and regular distances apart (1,000 feet is the best distance), but the placing of stations on local or artificial heights or hollows to be avoided. When done an explanatory remark to be entered in the field-book; such heights and hollows, if required for record, to be entered as intermediates, and the regular section to be confined to the natural surface of the ground.

(vi) As far as possible bench-marks to be described and not marked. Small boys in India as elsewhere are famed for their destructiveness, and special marks are almost certain to be observed by them, and run the chance of erasure or mutilation. A neat sketch of each bench-mark fixed to be drawn in the field book, the points of the compass being invariably shown on the plan, and the actual site on which the staff was held being indicated by a broad arrow thus ↑; the sketch to be accompanied by a written description and the reduced level.

(vii) When starting a section the level to be placed over the centre of the starting bench-mark, two or three ranging rods should then be fixed in an exact line by the telescope on the required bearing, the distance between the instrument and the farthest lining rod to be not less than 600 feet. The ranger to continue the line by fixing rods at intervals of about 300 feet apart, in the line given by the rods first fixed, which can be removed as the work proceeds, but the number

of rods in the line should at no time be less than three. The magnetic bearing of the line to be actually read and recorded for every station, both fore and back sights, and any variations corrected by re-starting the ranger on the true line. Men with clear sight are able to run a line in this manner with very fair accuracy, but the instrumental check should never be relaxed.

(viii) Obstacles to be passed by equal angles and distances. Thus ABDE (*Fig* 15, *Plate* X) represents the line on its required bearing; to pass the obstacle G set out an obtuse angle ABC sufficient to clear G, and make BC long enough to give a clear sight at D at an angle not less than 100°. Make CD equal BC and the angle CDE equal ABC; this can all be done by compass bearings. If care is taken the error in position of the line DE will be very slight, and can be checked if necessary by repeating the observations along BFD with the same or different angles and bearings.

(ix) An accurate survey to be made of all objects or features including waste land and other marked changes in soil crossed by the line, the exact chainage being noted. In addition, perpendicular offsets to be measured with the 10 foot rod to all remarkable objects which are within 300 feet of the line; the position of distant objects such as villages, temples, etc., to be fixed by bearings, not less than three sights being taken, and in order to ensure accuracy a prominent point in the object to be selected—drainage channels crossed by the line to be surveyed in for 300 feet on both sides of the line. (*See Fig.* 16, *Plate* X.)

12. Working with theodolite unnecessary for details on Canal surveys.—The Engineer accustomed to depend on his theodolite for the general work of a survey will no doubt consider the system described above rough and inaccurate, but it is surely true engineering to adapt the means to the end; and it must be remembered that a Canal project does not aim at the scientific accuracy of a Trigonometrical survey, requiring instead a minute detail of the ground surface, including the quantity and course of drainage water passing over it, together with the power of fixing locally the position of each observation; this is most economically and quickly given by the combination of fixed trigonometrical points and compass traversing.

The close approximation to accuracy with which compass lines can be run is perhaps not as well known as it should be. On some of the large projects already carried out in the United Provinces of India, lines, many miles in extent, run in circle levelling so as to rejoin the station they started from, have met within 5 or 6 feet—an error which is inappreciable in plotting at ordinary scales—and these small differences have been found the rule, not the exception, whenever the Surveyor has been careful and the compass in proper order.

13. Section check lines —As every two cross sections from the base line, when connected at either end, as they always should be, form a circle, there is ever present a ready check both for the levels and directions of the lines. These cross sections have frequently to be levelled by subordinates, and to prevent any chance of *fudging* or arrangement of levels to close correctly, the Engineer should level special check lines cross-cutting the sections. Thus, in the diagram (*Fig.* 17, *Plate* X) AB is the base line with its bench-marks from which the cross sections run at right angles, CCC is the check line, which starting from one B M. closes on another B. M. for its own check. By means of this line, pegs at random in any cross section can be picked up, and the correctness of the work checked with ease and certainty.

14. Trial lines.—Although the probable course of the Canal or Distributary can be located very close to the watershed when the Professional Map is properly prepared, yet before actually lining out it is necessary to run trial lines to fix the actual position for the lockspit. The Surveyor employed on this work should be supplied with a tracing from the Professional Map of that portion of the country with which he has to deal, with the probable course of the channels marked on it by the Engineer.

15. Starting point.—It is best to commence the trial line from the end not the beginning of the *doab:* the advantages of this course will be evident from a glance at the diagram (*Fig.* 18, *Plate* X) which shows the ordinary distribution of drainage lines in a flat *doab.*

It must be premised that the heads of the minor drainage lines shown in the diagram as falling into the main stream on either side, are frequently very difficult to recognize; and indeed in some cases where the ground is flat and the heads close together, it is clear that the Surveyor will be in much less danger of following a minor in mistake for the main watershed AB by commencing his trace at B, than he would be if he commenced at A.

16. Local enquiries.—To run a trial line the Surveyor should therefore commence by fixing a large peg at B in the position best suited for the tail of the proposed channel: then taking with him the most intelligent residents he can get hold of, and consulting his map, he should walk along the line enquiring from these men as he advances, regarding the directions in which the rain water flows, and marking at convenient intervals with ranging rods the line which he fixes on as the true watershed. Comparing his course with the levels on his map, the Surveyor will have very little difficulty in arriving at the true position of the watershed.

As the Surveyor advances the chain men can follow, aligning their course by the ranging rods, and keeping as close to the watershed as is consistent, with straights of about 500 feet between each staff and instrument station. After some time if the ranger of the party is intelligent, he can be entrusted with the advance lining out, the Surveyor returning to his instrument work, the ranger of course should return and consult with the Surveyor in all cases of doubt and difficulty, and should never advance out of sight or call. In working up a *doab*, following thus closely the watershed, the rise of the ground surface will be found remarkably regular except in particular situations, where for instance, the watershed has been cut away by river erosion—this regularity of rise gives the Surveyor still another check, and no marked variation from it should be passed over without careful enquiry.

17. Checks on compass bearings.—The true watershed is as a rule extremely tortuous, and the bearings of the trial line will consequently change at nearly every peg and require careful reading to serve as an accurate traverse. To check the line, bearings at frequent intervals ought to be taken of prominent objects, and connection should be made with cross section pegs and bench-marks when met with.

18. The survey.—The survey on trial lines needs particular attention. It is required as a guide to fix the position of the permanent line with reference to all objects through or near which it is undesirable to carry the channel, such as roads, village sites, wells, tanks, temples, etc., which ought to be surveyed in considerable detail when they are near the trial line, and where the traverse is for any reason off the watershed, the true line should also be carefully surveyed.

19. Interruptions to the watershed by village sites.—It must not, however, be supposed that the Surveyor can always carry his line strictly on the watershed. In addition to the necessity which occasionally occurs of leaving it for a time, to avoid extensive stretches of country in which

well irrigation is prevalent, physical causes often prevent the Engineer taking the canal line along the true watershed. Thus, it is well known to all Canal Engineers that inhabited sites are frequently situated exactly on the watershed, and that the artificial tanks, which have been dug to make these sites, and the mounds of *debris* accumulated year by year have in many cases diverted the drainage from its natural course. It is not an uncommon occurrence to find a village occupying the whole of a narrow *doab*—the houses built up to the very edges of marshes or tanks on either side—thus leaving no room for the canal channel. Again, a case may be met with where the *doab* is comparatively broad, but with abrupt slopes; here the village on the watershed so divides the drainage to either side, that the canal channel cannot be carried round the village without cutting off the outfall of its local drainage Such special difficulties have of course to be dealt with on the merits of each case and it will generally be found best to leave the watershed for a short distance and to provide for the intercepted drainage by a special cut or crossing. Another very good reason for avoiding the neighbourhood of village sites, is the saving of expense to Government and annoyance to cultivators consequent on cutting up the richly manured lands which generally surround homesteads.

20. Roads—Deep cut village roads are a common cause of the diversion of drainage across the watershed. In India metalled roads being comparatively a recent innovation, the local traffic, carried for years on the natural surface of the ground, has in numerous instances cut deeply into the soil; such roads in the rains become drainage cuts, and are further deepened by erosion.

A common example is shown in *Fig.* 19, *Plate* X, where the road, cutting through the watershed A, has drained the low ground B into the stream C, diverting it from its original and natural course to D. The close proximity of the watershed to the deep stream is not unusual, being the natural result of deposits from floods in previous ages, when the surface of the country was under formation. Instances are met with, where the drainage from B has to pass over a flat country for miles to find an outfall in its natural direction D; while on the other side it is only separated from a deep stream by a watershed a few hundred feet wide. It must not at once be taken for granted in such cases, that it is good engineering or advantageous to the country to divert the drainage to the deep stream; on the contrary, particularly in India, it is always much safer, as far as possible, to preserve the natural conditions. This is not merely because the people have suited their cultivation and habits

to their existing conditions, but for fear of unduly flooding certain streams and injuring or altering the supply of water to the subsoil, on the permanence of which much of the prosperity to the country may depend.

When however conditions formerly existing have been changed by the half natural action of traffic and erosion on the road, the determination of the best alignment for the canal channel is somewhat difficult. It is not improbable to suppose that cultivation in the low tract at B has increased owing to the improvement in drainage, and that the outfall past D has contracted from disuse; moreover, even if the blocking of drainage at A will not harm cultivation, it is pretty certain to flood a length of the road in the rains. The Engineer can take the channel along the false watershed between B and D which will entail a *possible* detour and *certain* embankment, besides losing command of the higher land near the true watershed: or he can keep the channel on the true watershed and arrange either to improve the outfall past D, or to provide an inlet or syphon at A. The last course is undoubtedly the best, but is only possible for small channels, and when there is no danger anticipated from obstruction by weeds.

21. **Sand hills and usar.***—The watershed line may be left and lower ground taken without hesitation when sand hills or bad soil is met with. In the former case the Surveyor avoids the certainty of loss from percolation without giving up any compensating advantages, as canal water is rarely taken in very sandy soils; nor is he, by avoiding high sand hills, likely to run his line into serious embankment. Stretches of bad soil again, though common, are not by any means universal, even in Northern India, and are rarely met with on the watershed, forming as a rule, a dividing tract between the good soil on or near the high lands and the low-lying or marshy lands of the drainage lines. (*See Fig.* 20, *Plate* X.)

There is some reason to believe that such lands, now uncultivable waste, were formerly covered with good soil which has since been washed down into the drainages below by the rainfall—the signs of this denudation are unmistakable in some places, but not easily recognizable in others. Pad soil is objectionable for canal channels on account of the difficulty of keeping banks made of it in good order. The objections to passing through it are not so great, when the channel is in digging, but it should, nevertheless, be avoided when this is possible with economy; and as above noted, this generally can be done by keeping to the true watershed. Indeed the Surveyor will do well to consider the fact of his getting his line mixed up

* Soil so impregnated with salts as to be unfit for cultivation.

with broken patches of waste and good land as a sign that it has left the watershed.

22. Breaks in the watershed.—The occasional juxtaposition of the watershed to rivers and streams has been noticed in paragraph 14.

Such watersheds have sometimes been afterwards cut away by the erosive action of the same stream that originally formed them. This causes a break in the continuity of the watershed, which necessitates an embankment for the canal channel, and though not as a matter of course, the crossing of drainage, the latter evil may sometimes be unavoidable to escape a long *detour*, but if possible the canal line should be taken along the secondary watershed, even at the expense of sharp curves, and an increase in length. Examples of breaks in the watershed of this class are not very common, but where they do occur, unless the general elevation of the watershed above the country be considerable, they are very puzzling; and it requires great care, and often many supplementary cross sections, to determine finally and in a satisfactory manner, the true cause of the apparently erratic flow of the drainage.

23. Permanent alignments.—When the trial line has been fixed, the laying down of the permanent line becomes a mere mechanical operation, which, however, requires both care and dexterity. The procedure includes five distinct operations, viz.—(1) Pegging out, (2) Lockspit digging; (3) Building bench-marks; (4) Levelling and survey, (5) Recording on village maps.*

24 Pegging out.—A suitable scale to plot trial lines is 8 inches to the mile. The bearings should be laid down on the plan with accuracy, and all the special survey shown in detail; the straights and curves for the permanent line can then be drawn on the plot, following as closely as possible either the actual trial line or the positions shown by the survey as most suitable. It is customary to take distributary channels out of the main line at an acute angle, say 45°, and a short length of straight near the head is useful as providing a site for measurements of discharge: it is also perhaps in some degree less liable than a curve to cause a silt deposit at the head. For the sake of simplicity in pegging out, if offset curves are used, all the curves should be arranged for offsets of one foot, six or three inches. Two-foot offsets † may be used for sharp curves on small minors, but only on exceptional occasions.

* The record on village maps can only be made when such maps exist.

† The offset for any chord or radius can be calculated by the formula—First offset $= \frac{\text{chord}^2}{2 \times \text{radius}}$, the last offset being the same as the first, and all others twice the first

The watershed, as before mentioned, will be found as a rule very tortuous, and consequently curves on the permanent line will be more frequent than straights, particularly on distributary and minor lines from which water is taken directly to the fields. In aligning the main canal, considerations of expense suggest that every effort should be made to keep the line as direct and straight as can be managed without interfering with drainage or running into embankment, where the country is very flat, this point becomes of great importance in order to avoid loss of head.

When the permanent line has been marked on the map, the distances in hundreds and thousands of feet and the bearings of all lines, including the intersections of S curves, can be measured and marked on, the scale (8 inches) being large, this can be done with very considerable accuracy. To set the line out on the ground the level should be set up at the head of the channel, and the line chained on the required bearing, a one-foot round-headed peg 1½ inches diameter being driven at every hundred feet, and a two-foot peg 3 inches square at every thousand feet. The square pegs should be numbered consecutively with the steel number sets, and deep circles dug round both these and the round pegs, as soon as the length of straight shown on the plan is set out. Ranging rods should be fixed on the two last pegs AA′ (*see Fig.* 21, *Plate* IX), when the leading chain man can measure the chord A′B and fix an arrow at B in the same line, then with the curve set or steel gauge he should set off the first offset BB′ at right angles to the line A′B, and then measure the second chord B′C in the direction given by the rod on A′ and B′, then set out second offset CC′, and so on, until the required length of curve is completed; the last offset being made the same length as the first. One or two chords short of the termination of the curve, the level should be set up, and a reading taken of the bearing of the chord, and these readings should be repeated until the bearing of the new straight is exactly obtained. This may not coincide with the exact length of the curve as shown on the plan, as it is manifestly impossible to obtain exact length on any drawing, however large the scale; but the variation will usually be small if the work has been expertly performed, and the new straight should be set out on the plan bearing, the plan itself being corrected so as to show the length of curve actually laid out on the ground—care must be taken to lengthen or shorten the straight, according as the curve was shortened or lengthened to obtain the correct bearing.

The sketches (*Figs.* 22 and 23, *Plate* IX) show the importance of attending to this point. In A the straight has been started from the termination of curve according to plan, but on an incorrect bearing, while

in B the bearing is correct, but the straight starts a little distance short of the calculated end of curve The slight misplacement of the straight in case B is of no practical importance, and can be easily compensated for in setting out the next curve It is not likely that even a careless Surveyor would deliberately set out a straight on a wrong bearing, but a beginner might not appreciate the importance of reading the bearing at the intersections of S curves—an omission of this check will have similar results.

The pegs put in for the trial line will always afford a ready means of verifying the correctness of the position of the permanent line: as soon as the latter is completed the trial line pegs ought to be pulled up as they are no longer required, and might in the future be the cause of errors.

The system of setting out curves by the formula quoted is an old one, but the practice of running the line continuously from one end, without intersections of straight lines, is, it is believed, peculiar to Indian Canal engineering; and is, moreover, a real necessity, owing to the extremely tortuous nature of the distributary lines, and the practical impossibility of always locating the intersections which will not unfrequently be situated in the midst of villages, tanks, or groves. Very often too the line has to pass for miles through high crops, for the destruction of which heavy compensation would have to be paid, were any of the ordinary systems of setting out adopted.

The use of an accurate steel gauge or curve set and sharp straight steel arrows of the same thickness is absolutely necessary to obtain true results. With good tools and a smart sharp eyed ranger the alignments will not be found inferior to ordinary theodolite work, while on the other hand the saving in time and expense is enormous, and the chainage continuous by one operation. In setting out main canal lines, the theodolite would probably be used by most Engineers, as long straight reaches of channel call for specially accurate work.

25. Lockspit—The lockspit ought to be dug as soon as possible after the alignment is completed, as pegs are liable to removal by villagers. To avoid vexatious interference of this nature where prevalent, the Engineer should take legal measures against injury to survey marks in a few cases—this will soon put a stop to this trouble To last for any time, in cultivated ground at least, the lockspit should not be less than one foot wide and 9 inches deep, of a rectangular section, and one foot on each side of the pegs may be left undug (*Fig.* 24, *Plate* IX), and the soil being thrown well away from the trench—the earthwork per mile will be 3,882 cubic feet.

To aid the Contractor in marking out the lockspit it is well to supply him with a dozen iron gauges (*see Fig* 25, *Plate* IX). The centre hole is put over the line peg, and the iron pegs in the outer holes are then driven into the ground, cords 100 feet long can then be attached as guides for the labourers. When sharp curves are being dug intermediate gauges should be fixed. This little precaution will make a great improvement in the appearance of the work.

26. Bench-marks.—The large pegs driven at 1,000 foot intervals on the permanent line have to be replaced by masonry pillars, as a peg however long, and apparently firm, is too liable to movement and decay to serve as a bench-mark for construction, which may possibly be deferred for a considerable time. The class of bench-mark usually built is a pillar 1½ to 2 feet square, top level with the ground, and 1 to 2 feet thick. This is often costly, and it is always difficult to ensure good execution of a large number of small scattered masonry works in a dry country: again if the pillar is small it has little cohesion and is liable to be destroyed, and if large the carriage of material is expensive. A better plan is to make bench-marks of the earthenware pipes (*colabas*) which are commonly used as outlets for canal water from distributaries. *Colabas* 6 inches internal diameter, 1½ inches thick, and 18 inches high, sunk with the top level with the ground surface, are not easly disturbed, and can be numbered by cementing circular earthenware figured discs inside the top. (*See Fig.* 26, *Plate* IX.)

The *colaba* can be fixed firmly in the proper position by driving four small lining pegs outside the large stake before removing it. (*Fig.* 27, *Plate* IX), and excavating the pit as near the size of the pipe as possible, and not deeper, so that the pipe may rest on undisturbed soil, water being used to consolidate the earth-filling. It will be found convenient to number each line separately from head to tail, commencing with 0, so that the numbering may show the length of each line in feet. In extensive projects mistakes in fixing the discs are likely to occur, on account of the great variety of sets which have to be dealt with, and the frequent necessity of employing illiterate men to fix the numbers. To avoid errors of this nature, it is only necessary to pack the proper number of discs for each line or section of line, in long canvas bags 7 inches diameter, the highest number at the bottom and the lowest at the top; the mason building the bench-marks, even if he cannot read, as he proceeds down the line, can then take each number out of the bag in turn and fix it correctly.

27. **Record on Village maps**.—When village maps are available the permanent alignments are marked on them in the same manner as cross sections, except that the point of crossing every field boundary is shown; the position of the 100-foot pegs need not be measured, but the bench-marks, with their numbers, require careful locating. Experienced men should be put on this work, as these field maps will hereafter form the basis of the land plans, and prove most valuable guides to the assessing establishment. When prepared in the field and returned to headquarters, the positions of the 100 feet pegs can be marked by scale and the reduced levels written in.

28 **Levelling and survey of permanent line.**—This operation, which completes the field work, is quickly performed by employing four staff men, two men keep to the 1,000-foot bench-marks, and two to the 100-foot intermediate pegs, the level being set up midway between the bench-marks and about 100 feet from the line. The back and fore staff are first read, and recorded in the usual manner on the lowest line of the first page of the Field-book; the man on the back sight B. M. No. 0 then moves forward to B. M. No. 2, and one of the spare men holds his staff on peg 100, then 200, 400, the second spare man is waiting at 500 and moves on to 900 in the same way—the level is then shifted. The work is very fatiguing to the intermediate peg staff men as they have to run between pegs to avoid delay. The 100-foot peg readings are entered in the intermediate column in the Field-book, and the rises and falls taken out with reference to the back sight on the B. M.; the reduced levels of the intermediates can then at once be obtained by addition or deduction from the reduced level of the back sight. The readings on the next pair of B. M's is entered on the eleventh line of the Field-book, and the check for clerical accuracy of calculations made for the bench-marks only.* The survey on permanent lines should not be undertaken at the same time as the levelling, which latter operation needs all the attention of the Surveyor, but should be a separate operation. Only special objects affecting the engineering of the line require record—such as buildings to be removed or altered, drainage channels, road and railway crossings, etc.

The general plot of the survey should be made on the Professional Map, enlarged plans being prepared of special details, when necessary, for facilitating the design of works.

29. **Field work when village maps are available.**—The foregoing remarks on field work apply in the main to country for which village

* See Example paragraph 4 of this chapter.

maps do not exist, and where the survey has to by made altogether by the Engineer of the project.

With these maps ready to hand cross section work may be omitted except so far as it may be required for a record in the future of subsoil water contours, and the only preliminary levelling operations necessary are those required to provide a system of check bench-marks. The major and minor alignments should be laid down by first making a traverse with the compass of the watershed lines found by the *doab* map, and then plotting these traverses on a scale not less than 8 inches to the mile: on plot a suitable permanent alignment should be marked off, pegged on the ground, and levelled exactly as described for the original survey working.

The main drainage lines should also be levelled up and any other portions of the country for which it appears necessary to acquire an exact knowledge of the reduced levels.

It has been mentioned previously that as a general rule the maps of villages are not founded on perfectly correct survey, and no doubt when making the alignment traverses considerable variations in distances and positions will be found to occur The plots of the traverses should therefore be looked on as the correct engineering records for Works and the *doab* maps as indices for practical irrigation, for this they are admirably suited In order to have a comprehensive view of the whole project, it will be necessary to plot the alignment traverses on one combined plan, on a small scale of say 2 inches to the mile—on this plan the positions of all works should be shown.

30 **Village water-courses.**—One of the great advantages of village survey *doab* plans is that the alignments and areas commanded by village water-courses can be determined with perfect accuracy once for all. The watershed for the channels, the soils, the culturable areas, the bounding drainages and the debarred tracts, are all graphically shown on the map, on a large scale, ready for entry in suitable registers so as to lead on to the calculations of area and discharge for minor and major distributaries, and eventually the main canal itself. This working up of the irrigation discharge from village water-courses to the main canal is the only correct foundation of an equitable irrigation system.

For the project it will be sufficient to take out areas and discharges, leaving the alignments and estimates of the water-courses until construction is put in hand. It may be mentioned here that under existing rules in India owners and cultivators construct the village water-courses. It would, however, be an immense advantage to the country if the first construction was carried out by Government agency, and the cost paid by

Government or recovered by instalments, as many of the evils complained of regarding canals and the delay in expansion of irrigation, are due to faulty and dilatory construction of water courses.

It has been mentioned previously that the lines of the main canal should be as direct as is consistent with correct engineering, and that distributary lines should closely approximate to the watershed, avoiding very sharp bends. The case of village-courses is quite different—they must not only follow the watershed absolutely, but should, in every case possible, occupy the divisions between fields and not cross or cut into culturable land where this can be avoided

31. River gauges.—While the survey is in progress it will be necessary to fix and arrange for the record of readings of gauges in all rivers and channels subject to floods. The reduced levels of the zeros of all gauges should be determined, and the readings thus entered in the records.

Temporary gauges are usually made by fixing a strong post with feet and tenths cut on it in the bed of the stream. Situations should be chosen where the post will not be carried away by floods. At times it will be found necessary to sink a brick well to carry the gauge, and in rivers subject to very high floods two or more gauges must be arranged so that the top reading of the lowest corresponds with the zero of that above it.

As a general rule, gauges should be fixed at or close to sites suitable for observing discharges, so that each discharge taken can be referred to a particular reading on the gauge. (*See Fig.* 28, *Plate* X.)

APPENDIX II.

INUNDATION CANALS.

1. **Weirs impossible.**—The simplest class of canal used in India is the Inundation Canal, of which many examples are found doing valuable work for the benefit of agriculturists, particularly in the Punjab and Sindh. These canals can of course only be constructed and used where the surface of the country to be irrigated is commanded by the levels of the river water from which the supply is drawn. A weir across the main river is never considered as even a possible expedient in the case of an Inundation Canal. Cuts are made from the river inland, for a certain distance, and are then carried in a direction generally parallel to the fall of the country, or the course of the river. By these, when the latter is in flood, the autumn crop is watered. Also before the river floods subside, the canals give the means of inundating some of the lands intended for the wheat and other spring crops, the further supply required to bring them to maturity being raised from wells. But owing to the depth of the sub-soil water often increasing with the distance from the rivers, the almost total absence of rain, and the insufficient number of canals, a very small proportion of the fertile alluvial tracts in the valleys of the Indus and its tributaries is at present under cultivation. During the cold season, labourers are employed to clear the canals of the silt which was left by the waters in their beds or heaped up at their mouths, varying from 1 to 6 or even 10 feet in depth. The irrigation is carried on by means of branch canals leading from the main one, whence the water is carried by minor channels on to the fields. When the levels do not admit of surface irrigation, the water is raised from the canal itself by the Persian wheel, or a temporary dam is placed across the channel to raise the level. Many of these canals have been made for the last 300 years, and are still in good working order, though kept so only by continual labour, their courses are very tortuous, following every winding of the ground, having been, in fact, laid out without the use of levelling instruments. The main channels vary in length from 5 to 50 miles, but they are generally too narrow for navigation.

2. **Heads.**—There are no works at the head to control the supply of water, for the course of the river is so uncertain, that it may completely

desert the head, and the water may have to be brought in by a new mouth excavated for that season, which again may be useless in the next, or the bank of the river may be cut away to such an extent as to involve the head-works in its fall. Under any circumstance, there is always a considerable deposit of silt at the head, which would naturally be increased by anything in the shape of a dam.

3. **Silt**.—The silt excavated from the bed during the cold season, is usually heaped up close to the edge in rough spoil banks, and is constantly falling in, while the tortuous course of the channel also causes large deposits of silt at the bends. The accumulation is still further increased by the water having no exit at the tail of the canal, which usually terminates in a series of small channels in the middle of the district. The labour of clearance thus becomes a heavy annual charge or drawback on the benefits received from the water, and the numerous deserted channels in various parts of the country show that, without such labour, these canals would soon silt up and become useless. But, in spite of all defects, they are highly prized by the people, and the Government has, at different times, made large grants of money for improving some and opening out others.

4. **Inundation Canal rules**.—Inundation canals require special rules for their administration and management. Although depending for their existence on the river floods, they are natually exposed to many dangers from the same source, and it is on the irrigating community, guided by professional advice, that must fall the task of protecting and maintaining works, which for financial reasons cannot be directly controlled by the State. The rules and system adopted for the Muzaffargarh Canals * in the Punjab, may be taken as a good example of the class of administration suitable for Inundation canals.

5. **Muzaffargarh Canal rules.**—These rules which are sanctioned by the Local Government, first specify the canals affected and the powers of various Government and village authorities, then authorize the collection and management of funds, the appointment and duties of the Committee of the Canal, and the conditions under which free labour shall be supplied by the irrigating community.

The rules also include regulations regarding the assessment of Canal revenue.

6. The notes by Mr. W. P. Brodie on these canals, quoted below, show very clearly the system on which Inundation canals are commonly worked.

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* *Vide* Punjab Irrigation Branch Paper No. 6.

General.—All the Muzaffargarh Canals—the Karm perhaps excepted—take out of river creeks and not out of the main stream. These creeks are common both on the Indus and Chenab, and should always, when practicable, be utilized as supply channels, for not only do they carry less silt than the main river, but they are much less liable to erosion.

The best position for a canal head is near the tail of a creek, as the channel is there most clean and stable, while should the head of the creek fail or get silted, a supply to the canal can be got from river back-water.

The up-stream angle of the take-out should always be something less than 90°, so that the canal may draw only the water it needs and not have an extra or excessive supply forced into it.

Silt.—Whenever heavy silt banks exist, a fault, either in alignment or water-way, may be looked for. In Muzaffargarh the most common fault is excessive waterway. This is due to forgetting the simple but important truth that the effective supply in a canal is not what it can take in but what it can pass on. Widening the head to increase the supply is an expensive mistake; what is needed when the supply is insufficient is to improve the draw. It is well to remember that if a head is too narrow it can be widened, but against a too wide head the water has no remedy save to throw down silt and reduce the waterway in the most objectionable manner by raising the bed. This silt is doubly troublesome; it is expensive to remove and it shortens the working season by untimely cutting off the supply.

When a head is too wide, the best remedy is to clear it by cutting a gullet of one-third the width with long slopes so as to establish a deep channel with a velocity higher at the centre than at the sides. This will encourage silt deposit at the sides, where it does no harm, and tend to keep the centre clean. This gullet should follow the line of deep channel, in straight reaches it should be in the centre, while in curves (which in inundation canals are often sharp) it should follow the outer bank.

These remarks apply to all heads—canal, branch and distributary.

There is generally a good deal of needless silt clearance done on these canals, and some further remarks are made on this point when considering *chher* labour and possible economies under it (*see* page 34).

Canal Heads.—Canal heads should be deep and comparatively narrow, the necessary waterway being obtained rather by depth than width. A deep channel has not only a higher velocity, but it gets a supply earlier and holds it later than a shallow one. Lower down, where the channel is coming to the surface, waterway may be got by widening so as to bring the depth down to a convenient figure. At the head, where the banks are high, a depth of water in the working season (excluding high floods) of 6 to 9 feet is suitable, but such depths might prove dangerous in a branch or distributary. By widening, however, they may be reduced to from 4·5 to 6 feet without loss. Moreover, by lowering the water surface, the hydraulic gradient—on which the velocity depends—is increased and may even be twice as great as the bed slope. Canal heads may therefore be narrower, but should never be wider than the channels they serve. This is true not only for canal, but also for branch and distributary heads.

Supply.—When at any point in a distributary the supply is insufficient, the proper procedure is to widen the channel at and above the point of insufficiency, so as to draw more water down. The widening should be to a fixed width (say from 5 feet to 6 feet) and carried out till it merges in the wider channel up-stream. In this way the poin

of insufficiency will either disappear or move up the channel to vanish at the head. Similarly, if a distributary, through no fault of its own, does not get a sufficient supply, the branch which supplies it should be widened at and above the off-take; and, if necessary, the point of insufficiency carried on into the main canal The principle to be acted on throughout is to work up from the tail and not, as is so often done, work down from the head, and to increase the supply by improving the draw. No head widening in distributary, branch, or canal should be permitted till the bed not only maintains itself clean, but shows slight signs of erosion

The insufficiency in supply here considered is assumed to be a real insufficiency, and not due to an excess share being passed lower down. The remedy in the latter case would be, not in widening, but in a stop-dam or similar device to check the excess

Distribution.—The system in vogue in Muzaffargarh is by internal *'tatils,'* the channel being divided into reaches which get water in turn. When working a reach the lower end is closed by a temporary stop-dam (a cross beam with planks, etc., and matting, known locally as a *kucha chháp*) which heads the water up and turns it over the fields. When the reach has had its *'wari'* or share of water, the stop-dam is removed and water passed on to the next reach These temporary stop-dams (*kucha chháps*) have been replaced in several instances by masonry stop-dams with *kurris* or needles (*pucka chháps*) and the alteration is a distinct improvement, for *kucha chháps* occasionally fail and then much time and labour are lost.

The system is certainly wasteful and inefficient, but as it is bound up with settlement rights the most that can be done is to try and improve it by removing unnecessary *chháps* and replacing those that are left by *pucka* ones This can only be done gradually, and requires local experience, and in doing it the leading cultivators should be freely consulted, as without their co-operation very little progress can be made. The positions of the *chháps* can sometimes be altered with advantage and in this way one *chháp* made to serve a double reach.

There is another way in which distribution can be improved, and that is by raising the bed in the tail length of a canal In former years tail branches were generally cleared unnecessarily deep, in fact the cultivators on one branch would work against the cultivators on another, their object being to get an undue share of the water. In such cases the distribution can be greatly simplified and improved by raising the bed, and as an instance of what may be done in this way the tail branches of the Puran Canal may be noted. The competition amongst these branches for a share in the water was so keen that they were cleared and deepened till their beds were little better than silt-traps, and the water surface so lowered that it was with difficulty it could be got on to the higher holdings This was remedied in 1891-2, when branch regulators were built and the beds raised about 3 feet, and since then distribution has been carried on without any trouble, and silt clearance has ceased. The tail distribution on many of the canals could be improved in this way, notably on the Magassin and the Rehru-Bihishti and Sardar branches of the Ghuttu Where regulators or masonry stop-dams exist, the bed can be raised by raising their crests, in other cases the necessary works can be built.

Another matter that deserves notice is the improvement of the outlets or water-course heads. These are mostly of a temporary nature, wooden frames with grass and wattles without any means of regulation, and are the cause of much waste of water. They tend also to weaken the bank through leakage, which during high

supplies sometimes develop into a breach. Some progress has been made in constructing masonry outlets, but much remains to be done, as the people are naturally disinclined to substitute fixed openings for temporary ones over whose waterway there is little control.

It is impossible on these canals to determine the size of the outlets with the accuracy attainable on permanent canals where the supply is regular and under perfect control When the rivers work at their best, irrigation on an inundation canal goes on smoothly and easily, but when the rivers rise late irrigation has to be pushed Moreover heavy rabi waterings are taken in August and September, while *kharif* irrigation is still in progress, so that outlets occasionally have to do double duty, and require accordingly a liberal allowance in their waterway For a rough approximation a square foot of waterway per 100 acres irrigated may be taken, but this would have local variations Where the holding was exceptionally low the waterway would be diminished, and when it was exceptionally high the waterway might be increased.

Development of irrigation —There is a good deal still to be done in Muzaffargarh in extending canal irrigation. Land is abundant, the culturable area at settlement being 1,418,135 acres, of which less than a third was cultivated The great hindrance to extension is want of enterprise and insufficient labour

From a financial point of view the most successful extensions are in villages under a fluctuating assessment, in which land newly coming under canal irrigation is assessed with a water-advantage rate In villages under a fixed assessment no increase in canal revenue takes place however much canal irrigation may be extended

Administration —The general system of administration is fully and clearly set forth in the Muzaffargarh Canal Rules, and all that need be done here is to make some notes on its practical working The first point is that the people have a much closer interest in the canals than obtains probably anywhere else north of Multan, they have been associated with them since their inception, they have given their lands freely for them, they annually labour on their clearances, and out of them, it may be said, they get their living. In working the canals it is important to bear this in mind, and to take the part rather of helper and advisor than that of a mere director The wishes and opinions of the leading cultivators should be freely consulted and there are occasions—for instance, in selecting the position for a canal head—when their local knowledge and experience are most valuable The more this local knowledge and experience are utilized the better, and to this end all schemes of work or proposals for alterations and improvements should be fully and openly discussed The Canal Rules make it imperative that the leading cultivators, under the name of *sarpanches*, should be consulted whenever *chher* labour is to be employed, but on all occasions it is well that the Divisional officer should relieve his mind of ideas and projects that may be simmering or forming in it by appropriate discussions He will in this way gain much helpful trust and confidence and find a reward in the smoothness with which his matured schemes will work. In short the more the people are identified with the canal, the more successful will the administration be—they will take an interest in its improvement, if it works well they will rejoice, if it fails they will take the failure in the same spirit as they accept other unavoidable misfortunes

Chheras and Chher Labour.—For the regulations regarding the assessment of *chheras* and the employment of *chher* labour, reference must be made to the Canal Rules, in which detailed orders and instructions are given. The assessments (known locally as *parta*) are made at committees of *sarpanches* held in September and are based on rough estimates prepared for each canal by the Sub-Overseers and *Daroghas*. These estimates

in their turn are based partly on past experience and partly on canal working—the better a canal works the less its need In November and early December working committees are held, before which the detailed estimates are laid, and on these, modified when necessary, the distribution of *chher* labour is made. These estimates should be carefully prepared, accurate levels being taken to determine the bed clearance, and detailed measurements made for bank repairs, etc It is here that a personal acquaintance with the character and condition of the different canals becomes of the highest importance. The tendency of the committee is to go on year after year doing the same clearances and repairs, thinking solely of maintenance and never of improvement On an average working canal the estimates tend to become stereotyped, there is no relief in the assessment and no improvement in the canal It is at this juncture that a Canal officer can act most usefully in detecting faults and devising remedies, by which labour will be lightened and efficiency increased With good local knowledge his engineering training and experience will bear with the happiest effect on the committee's deliberations.

In addition to silt clearance there is a great deal still to do in putting canal banks in order For inspection purposes it is essential that at least one bank on every channel should be rideable, and in Muzaffargarh such banks are the exception Some improvements have been made, but a continued effort is necessary to maintain progress, and an entry under the sub-head "Putting banks in order" should be made in the annual estimate whenever necessary This work can be done gradually.

Chheras are employed in two ways, either as daily labourers (*surh*) or on task work (*dák*), or partly on one and partly on the other Task work is best suited for work in a block and of a regular section—as for instance in digging a new head—as the tasks can be measured off accurately Silt clearance when of a regular section can also be done in this way. Its advantages are that it gives a certain outturn in work and that it dispenses with a record establishment and the use of attendance registers, etc. Its disadvantages are that the tasks are not done simultaneously, some men preferring to work in the beginning of the clearance period, some in the middle, some in the end, and some not at all, and there is also the difficulty in getting the tasks properly cleared and completed. Work unfinished at the close of a period is auctioned to contractors, the lowest bid being accepted, and the defaulting *chherguzar* has to pay this as well as a fine of the same amount Task work should not be enforced when the people are opposed to it.

In daily labour (*surh*) the outturn of work per *chhera* will not be so high as in task work, but the work will be properly finished, and the friction inseparable from task work will be saved. To ensure proper supervision, *chher* labour whenever practicable should be employed in large gangs and not scattered over a long length of channel The attendance and registers should be frequently checked and examined and attention given to the manner in which work is being carried out

Chher Papers and Accounts.—The various registers for the attendance and work of the *chheras* are very complete, and so long as they are properly maintained they protect the interests of both employer and employed. They are all in vernacular, and the Canal Officer should make himself thoroughly acquainted with them so as to be able to efficiently check them both on work and in office.

The accounts seems at first a little strange, but when their principle is understood they become easily intelligible. The number of *chheras* called out, the number remitted, the number present and the number absent are all straightforward entries. The first complication is due to what are called surplus or *fazla chheras* They arise in this way A *chherguzar* has to provide (say) 40 labourers. Inadvertently in the course of the working season he provides 41. He gets no credit for the extra man (the *fazla chhera*),

although the latter is of course entered as present in the register Another *chher guzar* who should provide 40 labourers provides only 39, leaving one absentee The account confined to these two men would then stand thus.—

Called out	80
Present	80 (41+39)
Absent	1

That is, the total of the present and absent may exceed the number called out.

The next point is the fines Absentees have to pay a fine of Re 0 8-0 each and in the accounts it might be thought that the number of absentees multiplied by 8 annas would give the amount in fines, but this is upset by fines on task work. In task work it is assumed there are no absentees, for if a man does not do his work he pays some one else to do it for him. While, therefore, the absentees are counted only on daily labour, the fines include both daily labour and task work For a canal on which there was no task work the fines in rupees would necessarily be equal to half the number of absentees.

Possible economies under Chher labour —A very fruitful field for economy was indicated in page 32 when considering head clearances. A characteristic of the committee is that they do not readily understand that a canal head may be too wide, and that if it were narrowed it would actually give them more water. They do not love innovation, and an innovation that reduces the waterway they perhaps dislike most of all. If a canal head has once been cleared to a width of (say) 40 feet they think it should always be cleared to that width, and will possibly at first resent any reduction A discussion in which the elementary principles regulating the flow of water are explained to them will, however, at least show them that the Canal officer in his decision is not guided by either caprice or thriftless economy.

Another economy in silt clearance will be found at the bends, which on an inundation canal are numerous. The bed there is always tilted, with the deep end next the outer bank, and the cleared bed should be similarly tilted and not cut out square and horizontal Even beyond the zone of silt clearance labour is wasted in this way by forgetting that at bends the working bed is never horizontal.

Another waste of labour is in customary bed clearance carried out in channels where ordinary silt clearance is unnecessary. Much labour is sometimes wasted in dressing the bed, removing surface irregularities and such like Any actual obstruction as fallen tree branches or jungle heaps should be removed, but generally it is well to act on the principle that if the water is satisfied with its channel there is no call to alter it. Moreover, this dressing work is particularly wasteful, as the men are necessarily scattered and do little beyond useless surface scraping. Any entry in the estimate under customary clearances should therefore be closely scrutinized and rigidly excluded unless good reason is shown to the contrary

Before finishing these notes it is proper to add that all committees should be made as open and public as possible. District officials, such as Tahsildars and Naib Tahsildars, and leading men, though not *sarpanches*, should be welcomed. Cultivators and others interested in the canals or the assessment have a right to be present, and any grievances or defects they bring forward should receive patient and careful attention

Floods and Flood Embankments —Standing orders regarding the action to be taken in anticipation of and during floods exist in the office and require no amplification here In former years the Indus gave the most trouble, but lately the Chenab has become

very aggressive, and more attention will have to be given to the readings of the higher gauges—at Wazirabad on the Chenab, and Chak Nizam on the Jhelum—during the flood season.

The flood embankments require attention so that they may be kept in proper repair and at full height above flood level. Work on them is done preferably by cold weather *chheras* as the work then is larger in quantity and better in quality. Urgent repairs or strengthening can be done in the hot season, but the labour then is not so economical or productive as it is in the cold season.

APPENDIX III.

PROTECTION.

1. Simple protection.—Simple protection to a tract of country means that artificial supply of irrigation which will make up for the deficiency in the rainfall in famine years, consequently for a district with a normal fall of 10 inches, the quantity of water required will be less than for one with 30 inches fall.

It will of course be understood that no canal could be constructed capable of supplying the actual quantity of water due to defects of even a few inches of annual rainfall over a large tract, nor could such a supply ever be required, as a large proportion of the rainfall always passes away without directly influencing crop growth.

In a 10-inch district the crops will be sown to suit the normal rainfall, they will require very little water, but may cover a large area. The real necessity for protection thus arises not from a low average, but from a fluctuating rainfall, for in a purely agricultural community without an imported supply of food, the number of inhabitants and the crops grown must suit the climate.

Besides the effects due to the rainfall the agricultural conditions of a tract are varied by—

(*a*) The class of cultivator.

(*b*) The soil.

(*c*) The advantages offered by means of artificial irrigation, such as rivers, tanks and wells.

(*a*) and (*b*) will often be fairly similar over large tracts and in a district with 30 inches annual rainfall, (*c*) will certainly be greater than in one with say 10 inches; indeed, in the latter case, unless unusual facilities for artificial tanks exist, there will not be any direct irrigation, except perhaps from wells, and as the supply to these also is derived from the rainfall, irrigation from wells will also be much restricted.

The agricultural conditions of a 10-inch tract therefore demand less water for simple protection than will be required in a district with 30 inches rainfall.

But it is also quite evident that canals can never financially or practically be utilized as a means of *simple* protection, for in years of normal rainfall they would not run at all, and with variable falls they would have to be changed in direction to supply particular tracts.

2 **The true protection required.**—The proper point to work to, is not merely to support an existing population, but to support as large a number as can live on the land without injury to it, or, in the other words, to raise each village up to its maximum point of agricultural efficiency.

It is evident that the number of people to be supported must constantly increase, especially when the condition of the village is prosperous; the disposal of the surplus is a matter beyond the scope of the Canal Engineer, but the point should be considered so far as not to give such a supply of artificial irrigation as would conduce to very small holdings, permanently irrigated, independent of the rainfall, and therefore extremely profitable

The model village might be described as one of moderate holdings self-cultivated, *i.e.*, cultivated by the owners or tenants and their families, with a certain fixed proportion of each holding artificially irrigated and dependent on rainfall, and with ample industrial occupation available for the labouring classes These conditions are rarely met with, and probably too Utopian to be commonly hoped for, but the general idea is the one which should be kept in view.

As a simple definition it may be said that a perfect canal system should increase the existing *permanent* irrigation facilities of a village to an area sufficient to enable the population, when at its maximum, to pay the revenue, the rent, and live in years of minimum rainfall.

3. **Crops.**—Once a canal has been introduced into a tract the agricultural efficiency becomes independent of the rainfall, and the quantity of water to be given depends on the soil and the cultivators

Independent of the rainfall, with of course two exceptions, *viz.*, when the rainfall is so high as to preclude artificial irrigation and when the canal supply is insufficient.

Artificial irrigation can never cope with the large area of cheap *kharif* crops which are usually sown in pure dependence on the rainfall. Small areas of these crops may occasionally be irrigated in years of very short rainfall, but this will be exceptional, and usually for the purpose of providing fodder, nor if irrigated under ordinary circumstances would the result be worth the expense. The irrigation system will, however, generally prove sufficiently elastic in years of very short rainfall, to take up that comparatively small area of high class crops often sown in the area dependent on the rainfall, in the hope of good rain bringing it to maturity; and this produce, together with that of the regularly irrigated area, should

suffice to maintain the village if proper calculations have been made. It will the more readily do so as the value of the produce will be increased in proportion to the defect in the rainfall.

Under ordinary agricultural conditions a village is divided into several distinct circles of cultivation, such as the highly manured, the lightly or occasionally manured, and the outlying land which is never manured. This division into circles is influenced by soil, proximity to the inhabited site and other facilities for manure, irrigation and superintendence. The boundaries and extent of these areas, each under a distinct style of cultivation and management, will remain unchanged for long periods, unless some strong influence, such as the introduction of canal water, causes a change in the conditions under which cultivation is carried on. This change may be merely an extension or alteration in site of the crops previously grown, or it may be radical and involve the substitution in great measure of wheat, sugarcane and indigo for barley, juar, bajra and gram, etc. The certainty of the irrigating supply will always encourage the cultivation of single instead of mixed species in the same field.

4. **Demand at different seasons**—Experience shows that usually on canals the demand for water is fairly regular throughout the year, except for short periods when general and sufficient rain falls

The area suitable for irrigation in the *rabi* or cold season may be larger than that available for watering in the *kharif* or hot and rainy seasons, but less water is required for the general run of cold weather crops than for the rice and sugarcane grown so largely in the *kharif*. Again, the supply available in rivers in the cold season is limited compared with the volumes supplied by the rapidly melting snow and floods of the hot and rainy seasons; there is consequently an elastic and self-regulating power inherent in permanent canals which can meet the fluctuation in demands for water in a satisfactory manner; and on properly designed systems the water available and the crop area sown will in time balance each other very fairly.

The great length of a large system has an advantage in balancing and regulating the demand, because the rainfall and the crop growth will both vary considerably in the different districts passed through.

5. **Percentage of area to be irrigated.**—If the considerations mentioned above are admitted, it is evident that we should determine the irrigable area not by the rainfall, but by the capabilities of the soil and the population; that it should be a percentage of the whole culturable and

not merely of the area cultivated under rainfall conditions; that it may safely be fixed by the year instead of by the season, and that it should not be so large as to encourage too dense a population or over-cropping of the soil.

It is simpler to work out this percentage for low than for high rainfall districts; for in the former case the villages are probably at so low an agricultural point, that whatever percentage is fixed will determine the degree to which the people and wants can advance; while in districts with high average falls, it is quite possible that a low percentage may not be equal to the demands of the existing population in a very dry. year.

Whatever percentage is fixed on should be that possible for existing permanent sources plus the amount to be added by the canal.

The question is a difficult and complicated one, and the case as worked out by the author for the extension of the Ganges Canal below Cawnpore (now called the Fatehpur Branch) is quoted here to explain the position more fully.

A careful consideration of the system to be adopted in these districts is of great importance, for—

(*a*) Here high class crops cannot be grown without water in ordinary seasons.

(*b*) A variation exists in present percentage of area irrigated in different villages.

(*c*) The quantity of water available from canals for the total area is small and unlikely to be increased; and

(*d*) This appears a good opportunity to attempt at least a settlement of the vexed question of "protection," as far as irrigation is concerned, for the districts referred to.

In this note *Maximum Percentage* means the maximum percentage of *malguzari* area in a village which may be irrigated without injury to the interests of the most improved systems of agriculture.

Minimum Percentage means that percentage of the *malguzari* area in a village the assured irrigation of which will in times of scanty rainfall render the village both self-supporting and able to pay its revenue demand, or, in other words, protect it.

Existing Percentage means the percentage of *malguzari* area in a village actually irrigated in 1289 *Fasli.*

Average Percentage means the average existing percentage by districts

It may be here noted that 1289 *Fasli* has been specially selected as a sample, because during that year there was little or no cold weather rainfall. Consequently well irrigation reached its maximum for such a year, while irrigation from other sources was naturally a minimum.

Irrigation from other sources in these districts means practically tank and *jhil* irrigation, and is clearly more to be considered a means of improving the outturn of crops in a naturally good season than as a certain source of irrigation in an abnormally dry year—in fact it is now practically rejected as a means of protection by the best authorities. We may, however, safely accept as permanent the small area irrigated in 1289 *Fasli.* Again, in a year like 1289, the actual area of irrigation from each well will be *less* than in a year of moderate rainfall, because the crops will require a greater depth of water and more frequent waterings, while the available supply in the well will be less. It is true that the *assami* cannot tell beforehand whether the cold weather rain will fail or not, and therefore will sow his crops for the average seasons, but the higher class crops are as a rule sown nearest the well, and *always* first watered; he is also well aware that there is more profit from one acre of first class outturn than from two acres of a medium crop, and, therefore, as the season advances, if no rain falls, he rejects the outlying inferior crops in favour of the higher class nearer the well. If the former have been even once watered, the return of area will be too great, but it is impossible to obtain perfect accuracy in statistical records.

The existing percentages are shown in black figures, *see Plate* VI, and the map has, for purposes of ready reference, been coloured (as shown in the scale) with a separate tint for each group of percentages.

It is evident that if we could raise every village from the existing to the minimum percentage, that the *doab* would be fully protected. This, however, pre-supposes the absolute* non-interference by canals with well or other existing irrigation, and forms the first principle of the proposed system.

This interference may be twofold*:—

1st. By a raised spring level destroying *kucha* or injuring *pucka* wells.

2nd. By the actual irrigation from the canal of well lands.

Interference due to the first cause can be easily remedied by repairs to the wells. It has been satisfactorily proved that the influence of the

* Except when the main canal or large branches cut off fields from a well; his case will be arranged for.

canal in raising spring level abnormally only extends to a distance of about half a mile from the low level channels, and it only injures wells where a layer of sand over the *mota* formerly dry becomes saturated.

It is also naturally most marked in very sandy tracts, which are uncommon in the districts concerned.

Wells thus affected and afterwards repaired will be capable of a higher duty than they were before the advent of the canal, but at the same time it is clearly only just that the canal capital should bear the cost of repairs.

It is proposed to obviate any chance of interference from the second cause by having lists prepared of all fields irrigated during 1289 *Fasli*, depositing them with both the Revenue and Canal officials, and debarring their irrigation under a heavy penalty.

The Canal Ziladar and his Amins will have no difficulty in identifying fields debarred from canal water if the numbers of such fields are entered in red in the field *khasra*.

It is also necessary to provide against any serious increase in the canal area allowed for individual villages to bring their existing up to the minimum percentage.

For this purpose an office *khasra* is required. It should be a copy of the *milan khasra* for 1289 *Fasli* with the following additional columns :—

Area.			*Percentages of—*			Area to be irrigated from canals.	Remarks.
Cultivated.	Irrigated	Culturable	Cultivated area irrigated	*Malguzari* area irrigated	*Malguzari* area to be irrigated from the canals.		
1	2	3	4	5	6	7	8

Columns 1, 2, 3 are simply totalled from the *milan khasra ;* they are intended merely to give a comprehensive view of the condition of the village prior to the introduction of canal water.

Columns 4 and 5 are calculated, and column 6 arrived at, by deducting the existing from the minimum percentage.

Column 7 is calculated from column 6.

In the first instance the entries should be made in the settlement *bigah* of the district; this is to avoid any chance of error and to provide a ready means of comparison with the patwari's *khasra* when necessary; but as all returns to Government are made in acres, it is necessary that the several areas should be reduced to acres, and for this purpose a spare line should be left to every village. It will be judicious to have a second

spare line also for the purpose of showing the condition of the village after, say, 10 years of canal irrigation. A very common result of the introduction of canal water is the cultivation of culturable land; this occurs generally when such land is of poor quality, not offering any chance of profit from expensive well irrigation. With this *khasra* and the return of irrigation by villages before him, the Executive Canal officer can at once detect any serious error in the authorized distribution.

Under the present canal system of *almost* free sale of water at fixed rates, it is manifestly impossible to arrange that each village will irrigate exactly the area allotted to it even with the heavy demand which we have reason to expect in these districts. Moreover, the varying nature of the cultivators and soil in different villages would render the issue of a hard and fixed rule injudicious. If sufficient canal water is available, the system of distribution by main channels should certainly be based on the minimum percentage, but it is evident that a maximum percentage should also be fixed in order—

(*a*) To determine a point which should not be exceeded by canal irrigation under any circumstances.

(*b*) For the purpose of absolutely debarring from canal water all villages where existing percentage equals or exceeds the maximum percentage.

If maximum and minimum percentages could be fixed and worked to for all districts having canal irrigation, the result would probably be a vast increase in the total area of irrigation for the Provinces, for the canal water thus liberated could be utilized in dry tracts with a percentage below the minimum, and from the favourable results of recent experiments there is reason to hope that well irrigation would very rapidly replace the debarred canal irrigation.

Thus, though it appears necessary to fix a maximum percentage, yet, every effort should be made to work to the minimum percentage.

It is not an easy matter to fix either the maximum or minimum percentages. The District Officers, with an intimate knowledge of their districts, to which I cannot pretend, are undoubtedly best fitted to give an opinion. I will endeavour, however, to give some grounds for the figure I propose, and at the same time I may add that these figures have met with the approval of some of the most eminent authorities on the subject.

The following are the average percentages (for 1289 *Fasli*) of the more important (in an irrigated sense) districts of the United Provinces :—

Average=19·2.

Moradabad ..	2·8	Agra ..	22·3
Bijnor ...	3·7	Muzaffarnagar ..	24·4
Budaun ...	5·8	Meerut ...	25·9
Pilibhit ...	6·4	Farrukhabad ...	25·9
Bareilly	13·3	Etawah ..	27·0
Shahjahanpur ..	13·6	Etah	27·0
Allahabad ...	13·4	Basti ..	32·2
Saharanpur .	15·0	Cawnpore ...	34·0
Fatehpur ...	16·5	Aligarh	40·4
Mirzapur ...	17·0	Mainpuri ...	43·4
Bulandshahr ..	18·2	Ballia ...	50·0
Gorakhpur ...	20·9	Azamgarh ..	58·7
Muttra .. .	21·7	Jaunpur ...	71·8

They vary greatly, but every district should be considered both with reference to its needs and its facilities.

Thus in Saharanpur and districts like it prior to advent of the canal the irrigated area was probably very small, as most ordinary crops could be raised without artificial watering. The canal, when introduced, brought with it higher classes of crops needing irrigation even in naturally damp districts.

In 1289 *Fasli* I saw in Muzaffarnagar wheat grown without irrigation equal to that usually given three to four waterings in Cawnpore.

In such damp districts the minimum percentage will be higher than the average, even where irrigation is general and equally distributed, and *self*-protection becomes financially impossible, for in ordinary years the people will not fully utilize the means of irrigation provided for them on the standard requirements of an extraordinary dry season. While in dry districts the minimum percentage of area will always be fully worked to, although with good cold weather rains the number of waterings given will be less..

Another difficulty with regard to *damp* districts is the large area of sugarcane and rice usually grown there. These require such quantities of water in very dry seasons that unless they are debarred in favour of other food-crops, the calculations of area capable of irrigation from a given quantity of water are completely thrown out.

Protection by a minimum percentage appears therefore practically impossible in damp districts with a mild climate. The comparative cheapness (as far as irrigation is concerned) with which crops are raised, and the great profits derived from the cultivation of higher class crops, should render the people somewhat independent of a bad season. Unfortunately from the nature of the cultivation much cannot be hoped for from this source, but as crops can be raised with less actual outlay in such districts, when the cost of watering is determined by the quantity of water used (as in the case of wells and other sources), these districts should be able to bear a high wet-rate, and protection may be secured by capitalizing the excess over ordinary rates.

This system would apply also to the greater part of the canal watered area, for although the canal rates are charged per area and not per quantity of water used, yet in the more northern districts watered by the Ganges Canal a lower rate is charged than in the drier tracts commanded by the Lower Ganges Canal.

Apart from climate, the geographical position of a district, with reference to the great rivers, has a considerable influence on its average percentage. This is particularly marked where the district is bounded for a considerable distance by the Jumna. The distance from the ground surface to the level of sub-soil water is usually very great near this river, and there are few facilities for building wells.

The numerous ravines also to a certain extent hamper the distribution from canals, and the average for the district is consequently considerably reduced by the low percentage of the bounding villages.

The Ganges has some, but not so marked, an influence in reducing the average percentage as the Jumna.

In a district with few villages having less than the minimum percentage the average will evidently be greater than the minimum percentage

I think we may assume Aligarh as a fairly protected representative district, for—

(*a*) Canal irrigation is long established and evenly distributed.

(*b*) There are ample facilities for well irrigation, and the class of well irrigation is perhaps on the whole the best in the Province.

(*c*) It has a very small great river boundary.

(*d*) Although compared with Cawnpore, Fatehpur and Allahabad, the necessity for artificial irrigation is not so great, yet there is a very even and well-sustained demand.

The average percentage of *malguzari* area for Aligarh = 40·4.

16 per cent. of the *malguzari* area is uncultivated or, in other words, for every six acres of cultivated land there is one acre of grazing land.

The average percentage of cultivated land = 47 per cent.

It is hard to conceive, and still more difficult to put on paper, a clear view of the position of any village with reference to its *rabi* and *kharif* cultivation, and apart from the influence of irrigation.

It is complicated by—

(*a*) Variations in soil, climate and cultivators.

(*b*) The cultivation of sugarcane, indigo, *sawan* and rice.

(*c*) *Dofasli* crops.

In the normal village without canal irrigation, and with little from other sources, the village site was naturally placed near the best *mota*, or, in other words, where the greatest facilities for well irrigation existed; even now the influence of a good well on the growth of hamlets may often be observed. In such a village the manure circles were a matter of course somewhat concentric to the village site, and the outlying *har* was usually devoted to ordinary *kharif* or *rabi* crops not requiring irrigation. The introduction of a canal alters this, and the whole area of the village becomes more or less broken up into a series of *chaks*, generally corresponding to the average holding, each with its separate *kharif* and *rabi* cultivation.

The *Dofasli* area cannot be clearly shown in the existing form of the *milan khasra*, and this to a certain extent invalidates the return of irrigated area, for a field twice irrigated for separate crops is shown at double its proper area.

If we consider the case of a village of, say, 1,000 acres cultivated area, the following may be considered a fair division of the area :—

	Acres.
Rabi	400
Kharif	500
Fallow	100

The relative percentage of *kharif* to *rabi* of the villages examined by me during 1289 *Fasli* in Aligarh varied from 60 to 40 per cent. *kharif* to *rabi*. Considering sugarcane as a *kharif* crop, 5 to 4 may be, I think, allowed a fair proportion.

I doubt that 10 per cent. of cultivated area is left fallow in many villages; but in the interests of good cultivation a much larger proportion of area should be given rest, and this point is of importance in considering the case of the maximum percentage.

If we take 50 acres of sugarcane as the annual cultivation of that crop for the village we must reduce the total *kharif* area to 475 acres, as the area under sugarcane should certainly get rest for one whole year in addition to the 10 per cent of fallow allowed.

Now in the case of the *average* percentage for Aligarh we have 47 per cent. of 1,000 acres, *i.e*, 470 acres of irrigation (less *dofasli*, which may safely be neglected) to divide into—

	Acres.
Rabi	400
Kharif	475

The following percentages of crops were grown in Aligarh in 1288 *Fasli* :—*

		Class I	
Kharif	Crops not generally irrigated, (mixed).	*Juar* ... ... *Bajra* ... ... *Arhar* ... ... *Urd* ... ... *Moth* .. ... Cotton and *Arhar* Miscella neous ...	75 per cent
		Class II.	
Kharif.	Crops usually irrigated, food	Maize ... ... Sugarcane ... Rice .. ... Garden crops ...	13 per cent.
		Class III.	
	Crops usually irrigated, non-food	Cotton ... ... Indigo	12 per cent.
		Total ...	100

		Class I.	
Rabi	Crops not generally irrigated, food ...	Gram ... ... Peas ... ... *Masur*	6 per cent.
		Class II.	
	Cropsus uallyirrigated, food ...	Wheat ... ... Barley ... ... Wheat and gram ... Barley and gram ... Potatoes .. ... Garden ... ... Miscellaneous ...	92 per cent.

* I have not at hand the percentage of 1289.

Class III.

Rabi	Crops usually irrigated, non-food	Opium ...	...	2 per cent.
		Tobacco ...	...	
		Garden	...	
		Miscellaneous	...	
		Total ...	100	

For our type village I would somewhat alter these figures in *kharif* increasing Class II to 20 per cent., to cover a large area of sugarcane, which, if the land is good enough, will always increase with assured irrigation. Class III in *kharif* must suffer in famine years: I would therefore reduce it to 10 per cent. for the minimum percentage, increasing it to 20 per cent. for the maximum percentage to include the cotton grown with *arhar* in Class I.

The *rabi* may be considered as all irrigable; but of the 92 per cent. in Class II a large area (over one-third) is under gram grown with other crops, and with assured irrigation the gram would probably be grown separately.

In 1288, 60 per cent. of this *rabi* area was actually irrigated, and we cannot be far wrong if we assume that the village will be protected from the worst consequences of famine if 50 per cent. of the *rabi* area is supplied with assured irrigation, the maximum percentage will vary within wider limits, but I do not think it would be fair to the land to allow more than 70 per cent. of the *rabi* to be annually irrigated.

Only 30 per cent of the *kharif* area is assured in bad years; but it must be remembered that this 30 per cent. comprises most of the higher class crops requiring large quantities of water, and that if these were given up a much large percentage of area of inferior food-crops could be saved.

If these percentages are accepted we find the following result:—

Minimum percentage.

		Acres.
50 per cent. of 400 acres *rabi* area ...	... =	200
30 „ 450 „ *kharif* „ ...	... =	135
Total	...	335

335 acres irrigated out of 1,000 cultivated = 33·5 per cent.

Adding ⅙th to cultivated we get 1,166 acres of *malguzári* area.

335 acres irrigated out of 1,166 *malguzari* = 28·7 per cent.

Maximum percentage.

		Acres.
70 per cent. of 400 acres *rabi* area ...	... =	280
40 „ 450 „ *kharif* „ ...	... =	180
Total	...	460

460 acres irrigated out of 1,000 cultivated = 46·0 per cent.

Adding $\frac{1}{6}$th to cultivated we get 1,166 acres of *malguzari* area.

460 acres irrigation out of 1,166 *malguzari* = 39·4 per cent.

As far as canal distribution is concerned, the inequality between the *rabi* and *kharif* requirements for water is not so great as it appears, for sugarcane and rice, the main *kharif* crops, are seldom watered from wells, while all the *rabi* crops are commonly thus irrigated: about the same quantity of water will, therefore, be required for the *kharif* and *rabi*.

An important point with reference to the minimum percentage to which my attention has been drawn is the great increase in value of the crops grown during famine times; this enables us to considerably reduce the crop area without financially injuring the prospects of the village.

Thus, as far as concerns Aligarh, it appears safe to assume that the minimum percentage is 30 per cent. and the maximum 40 per cent., and I think that 35 and 45 per cent. respectively, may be safely accepted for Cawnpore, Fatehpur and Allahabad; for, although the climate of these latter districts is drier than that of Aligarh, yet they are not so liable to fluctuations in rainfall, *vide* Sir William Muir's opinion, Government Proceedings, Public Works Department, September, 1869, No. 62, paragraph 6.

The approximate gross areas commanded in each districts are—

	Square miles.
Cawnpore	100
Fatehpur	700
Allahabad	300

Deducting 25 per cent. of waste we have—

		Acres.
Cawnpore = 75 square miles ...	=	48,000
Fatehpur =525 „ „ ...	=	336,000
Allahabad =225 „ „ ...	=	144,000

Area commanded by canal.

District.	35 per cent. of area commanded in acres.	Existing per cent. in 1289 *Fasli*.	Area irrigated in 1289 *Fasli*	Balance area for canal.
Cawnpore	16,800	20 per cent.	9,600	7,200
Fatehpur	117,600	10 "	33,600	84,000
Allahabad	50,400	10 ..	14,400	36,000
Total ..	184,800	..	57,600	127,200

If we take the duty of one cubic foot of water per second at 250 acres, as I think we safely may for these districts, we find that 500 cubic feet should irrigate 500 × 250 = 125,000 acres, which result agrees curiously with the approximate requirements.

I have, however, great doubts as to the accuracy of this result. A deduction has also to be made on account of the Pandu-Ganges *Doab*, and I should myself recommend that the distributions should be based on a minimum of 30 per cent. with a maximum of 45 per cent. and a duty of 300 acres per cubic foot.

There is a considerable area of *kabár* soil in the Fatehpur and Allahabad districts along the Jumna bank. It is a question as to whether this soil will bear canal irrigation or not. Some of it is irrigated from wells, and I think the experiment might be tried in view of the extraordinary fertility of such soils when watered.

APPENDIX IV.

REH.

1. **Usar.**—A very large area of the soils of Northern India contains in more or less excess, highly soluble sodium salts—chlorides, sulphates, carbonates—the result of the decomposition by air and water of the particles of rock minerals to be found in every soil. In the United Provinces alone the area thus injuriously affected as respects cultivation amounts to about three million acres, and as this area is not an isolated tract, but is often scattered in detached patches throughout high cultivation suitable for irrigation, and often irrigated, the subject is one which demands the particular attention of the Canal Engineer, both as regards the reclamation of the existing bad lands and the prevention of the spread of injury to lands not injuriously affected.

The salts referred to are locally termed *Reh* or *Shora,* and the lands affected *Usar*, *Kallar*, *Kalrati*, etc.

2. **Distribution of Usar.**—The quantity of *reh* free in the soil varies greatly in different localities; almost all soils contain it to some extent. It is found in excess on the great salt plains of Utah, where the energy of the Mormons has successfully coped with the difficulty When at its worst in India, places may be seen covered with a white efflorescence like snow,* in other localities the salt does not show free on the surface, but the soil is hard and unkind in appearance. *Usar* also varies in extent from large tracts bare of cultivation to small patches isolated amid rich cultivation.

3. **Theory of the formation of usar lands**—Dr. Watt considers that when water, whether rain or canal or well water, sinks into a soil containing these salts, it dissolves them and carries them down till it reaches an impermeable stratum. If the soil is highly porous, they are washed down to the underground water. If this has a ready outlet they are removed: if not, they remain in solution in the underground water which becomes saline (brackish). If the underground water level is deep they do no harm; if it is near, they are brought to the surface by capillary attraction and deposited in the form of white crystals by evaporation, and in this form are destructive to crops and to natural vegetation. This theory of the formation of *usar* lands is generally accepted, but I consider that a very marked distinction must be made between the two cases, *viz*, that in which the water from above actually reaches the underground

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* These salts are often collected by being swept into heaps for the coarse glass manufacture common to Northern India.

water, and that in which, as is very frequently the case, it never reaches that point, being merely absorbed in the soil to be again evaporated or partially absorbed, the excess being carried off by surface drainage.

In the first case when the water percolates down to the sub-soil from the surface, as it carries the dissolved salts away, the quantity in the soil above must be gradually reduced in time, and the action of the rainfall alone in certain localities can improve the soil to culturable quality. If the amount of *reh* present originally in the soil was small, no trace may remain of this action having occurred, because the salts will be greatly diluted in the vast underground reservior which is always slowly moving. If the amount of *reh* was large, or if the action is still in slow but steady progress, the sub-soil water ought to be impregnated with salts; again, when the surface is not a local source of supply to the subsoil reservior, yet is heavily impregnated with *reh*, the underground water should be sweet. Now these very conditions are frequently found to occur—for example in the Muttra district of the United Provinces there is but little *usar* on the surface, the soil is highly cultivated, but the wells in places give such brackish water that they cannot be used for irrigation to germinate the crop, though the saline quality is considered beneficial for some crops during certain stages of growth. Again in the Etah district, *usar* of the worst type exists interspersed with cultivation, yet the wells sunk for irrigation, even when in the *usar* land itself, generally give sweet water. In this and many other districts of the United Provinces where *usar* is prevalent, it is interesting to note that it does not show any strong tendency to spread into the adjoining patches of cultivation. Fields, like islands, surrounded by *usar*, are often permanently cultivated, and do not appear to suffer injury unless flooded during the rains by water off the *usar* tracts. Mr. H. S. Reid (Board of Revenue's Minute on *Reh*, dated 1874) states: "Patches of barren land are found in the very centre of cultivated fields . . . The balance of testimony is certainly in favour of the theory that the position of the barren spots does not change."

It may be said generally, that *usar* tracts when bad are not sources of supply to the subsoil water. *Usar* rarely occurs in sandy soils, being confined to loam and retentive clays.

4. **Reclamation of usar lands.**—The successful reclamation of *usar* lands by irrigation from the Chenab Canal carried out in the Gujranwala district,* is a most instructive instance of the power a plentiful supply of water has of washing the salts out of the soil. Here were large tracts

* *Vide* Punjab Irrigation Branch Paper No. 4, "Reclamation of Usar Soils."

near the head of the canal which had never been cultivated, and which the Zamindars declared were unculturable. The rainfall of this tract varied from 10 to 20 inches annually, and it is evident that this alone was insufficient to wash out the soil, but it was found that rice cultivation which involved a large supply of water banked up on the land, in time brought the soil into a condition fit to produce all classes of crops. Indeed, so marked was this improvement, that it was found that cultivators, always quick to discern a real advantage, were deserting the older settled lands in favour of the more profitable reclaimed *usar*.

The rainfall in Gujranwala is less than half the annual fall of the Muttra and Etah districts, and therefore the latter and other tracts like it, with confirmed *usar* and ample rainfall, may be assumed generally as incurable by simple irrigation, owing to the retentive nature of the upper strata, even if water is poured on in excess. The Muttra district on the her hand may, with some show of probability, be taken as a sample of a tract cured by natural means. It is, however, possible in several ways to improve *usar* lands of the worst type and render them even culturable, but the expenditure involved is generally greater than can be repaid by the eventual profit, the question is one of great interest, owing to the extent of these lands and the demands of an ever increasing population.

Simple enclosure by a fence to prevent grazing will allow of the growth of the natural grasses which can be cut for hay. After two years, experimental cuttings gave as a result 14 cwts. per acre, but the cost of fencing is a serious item, and the value of the grazing which would otherwise have benefited the village cattle to some extent, must be deducted from the outturn to arrive at the true profit.

Manuring and deep cultivation have also proved successful by bringing *usar* lands into a productive condition, but here again the expense of the process and the difficulty of providing manure in large quantities are objections which deter the cultivating classes from progress in this direction.

Reh-infected lands have been improved by enclosing them with low banks and warping up with silt laden water from canals or river floods; the deposited silt is in itself a valuable addition to the soil, and a proportion of the salts must be carried away by the water. It is even possible that the head of water thus applied may force a connection with the subsoil water table and thus effect a permanent cure: this remedy should, of course, not be applied when there is danger of injuring existing cultivation by swamping from percolation, or well irrigation by making the subsoil water too saline for use.

A stratum of *kankar* embedded in heavy clay is very often found in *usar* land a short distance below the surface. Where this occurs and the *kankar* can be profitably disposed of for roads or lime manufacture, it is probable that its complete removal from the soil, combined with the sinking of pits at intervals through the clay to the sand which usually lies below, would give sufficient sub-soil drainage to make the land culturable.

5. Distribution of Reh and Usar. –The following very interesting and instructive Note on the Distribution of *Reh* and *Usar*, by Mr. (now Sir Edward) Buck, K.C.S.I., written in 1874, is reproduced here by permission, as it contains many points worthy of full consideration of Canal officers having charge of canals in *reh*-infected districts.

The large area of land rendered uncultivated both in these provinces and in the Punjab by *reh* has long attracted attention, and the subject has continually induced speculation and enquiry.

The questions which require solution may be ranged under three heads :—

(1) What is the origin and nature of *reh*?

(2) What are the laws which govern the distribution of *reh*?

(3) What, if any, are the means by which *reh* can be removed, and by which *reh*-impregnated land can be brought under cultivation?

Many replies, more or less conjectural, have been given to the above questions, but hitherto very few facts have been collected in support of any of the theories which have been advanced. The principal object of the present paper is to bring together as many facts as possible bearing on the subject.

The origin of *reh* is obscure, and must probably be sought in remote geological history ; at any rate, no facts are now adduced throwing light upon this portion of the subject.

The nature of *reh* has been to a certain extent ascertained: specimens have from time to time been analyzed, and the results may be summed up in the words of Mr. W. J. Ward, the English Chemist, to whom certain specimens were submitted for analysis, that "*reh* is a mixture of highly soluble salts"*.

There is no doubt that what is called *reh* is by no means the same mixture in all parts of the country. This is proved both by the analysis of different specimens, and by the fact that even in the same district the *reh* of one part can be employed for certain purposes (such as the manufacture of soap, etc.) for which the *reh* of another part is useless.

The mistake is sometimes made of including under the head of *reh* the efflorescent nitrates often found in small patches of land which are either the sites of old habitations, or are the recipients of the liquid manure of existing villages. This mistake is liable to lead to wrong conclusions ; three officers, for instance, in replying to some questions lately issued by the Board of Revenue on the subject of tobacco cultivation, reported that *reh* was used as manure, which proved on inquiry to be really nitrate.

There is no reason to believe that *reh* in small quantities is injurious to vegetation.

The next question, viz., what are the laws which govern the distribution of *reh*, is one which has given rise to many theories. But it is reasonable to suppose that a sufficient number of facts must exist to show which is the true theory.

* The analysis is given in detail in the Board's Revenue Reporter, Vol. III. No. 2, 1869.

Mr. Ward, whose report has already been noticed, has explained in a few lines the simple physical law which must govern the distribution of *reh* :—

"*Reh is a mixture of highly soluble salts,*" he says, "*and water is the vehicle by which all its movements in the soil are affected, and it is the general direction of water in the soil which determines that of reh*"

There is nothing in the replies of any officer consulted to controvert this statement There is much to support it. It is difficult indeed to understand how it could be contradicted. Now it is evident that if *reh* is carried about by whatever water comes into contact with it, the problems to which the inquiry must be reduced are the following:—

(1) What water comes into contact with *reh* ?

(2) Where does that water go ?

It occurred that for a term of nearly three years my official duties, as Settlement Officer of Cawnpore and Farrukhabad, obliged me to inspect in very close detail a tract of land, about 40 miles long and from 10 to 20 miles broad, full of *reh*-infected soil and traversed by the canal

I happened to take especial pains to record every fact, however small, which came under my notice in connection with *reh*, in order that I might ascertain from actual facts—

(1) In what places *reh* appeared.

(2) What laws governed its distribution

(3) What disturbing effect was exercised by canal irrigation

I sometimes stayed for two or three days in one place for the purpose of ascertaining and recording the circumstances under which *reh* had appeared. I entered upon the subject without any pre-conceived ideas, and derived my conclusions entirely from the facts which came under my observation. I found by this inductive process that *reh* is distributed solely by water which has the opportunity of coming into contact with it, and is carried into those places only into which such water has access

This conclusion agrees, as it ought to agree, with the physical law given by Mr. Ward, and though it appears almost too simple to be worth recording, yet simple as it is, one essential point in it has been overlooked. The general proposition has indeed been made over and over again, that the distribution of *reh* is influenced by drainage, but no consideration has been paid to the fact that a very small portion of the drainage of land can come into contact with *reh*, and that the range of such drainage is extremely limited.

I propose to explain by a series of simple illustrations the manner in which water is brought into contact with *reh*, and the natural process by which *reh* is distributed, and to bring forward the facts which I have collected as examples and evidence of the process.

I assume that the process by which evaporation brings salts to the surface of moist earth impregnated with saline matter, and leaves them on the surface in a condition of efflorescence or crystallization, will be accepted as an axiom.

The following illustrations will show how this process is combined with the action of surface drainage in determining the distribution of *reh* :—

Let *a.....g* (*Fig.* 109, *Plate X*) represent the section of a tract of land equally impregnated with *reh* and moisture in all its parts.

Let *ab*, *cd*, *ef*, denote depressions of 2 or 3 inches in depth, and *bc*, *de*, *fg*, elevations of 2 or 3 inches in height in its surface, which is otherwise level.

Let *reh* be represented by dots, the closeness of which roughly indicates its relative amount.

Then suppose that the heat of the sun acting upon this tract of land for several months brings a certain amount of *reh* to the surface by the evaporating process.

The diagram (*Fig.* 110, *Plate* X) will represent the appearance of *a......g*

Now let a shower of rain of one inch fall upon the land, the first shower of the rains in fact It will take up the whole of the efflorescent *reh* in solution. Some of the *reh*-infected water will sink into the ground, where it falls, whether on the elevations *bc*, *&c*, or on the depressions *ab*, *&c*., but a great part of the water which falls on the elevations *bc*, *de*, *fg*, will flow into the depressions *ab*, *cd*, *ef*, and sink in them

A certain quantity of *reh* will be removed therefore from *bc de*, *fg*, and carried into *ab*, *cd*, *ef*; and as the tendency of water is to sink vertically into the ground, a greater quantity of *reh* will be carried below *ab*, *cd*, *ef*, than below *bc*, *de*, *fg*

After the shower, then the condition of the tract may be represented by the diagram (*Fig.* 111, *Plate* X)

The *reh* is now all under ground Now suppose the second shower of the rains comes down,—what happens? If there has not been a sufficient interval of sunny weather to bring any *reh* in efflorescence to the surface (and as a rule there is not a sufficient interval), this second rainfall does not come into contact with any *reh* above ground, and cannot therefore, like the first shower, alter the distribution of an *reh* in a horizontal direction on the surface It sinks into the ground, and probably carries some *reh* deeper than before in a vertical direction downwards, but even under ground it has but little horizontal action.

Suppose a more extreme case After the second shower let heavy rains fall and cover the plain *a......g* with water a foot deep, which flows off gradually down a drainage line into a river

Does not this water carry away any *reh*?

No, for except so much of it as sinks into the ground, *none of the water comes into contact with reh.* The water which flows off horizontally over the surface is almost as clean and pure of salt as if it has fallen on the best soil in the country.

Now suppose the rains brought to a close The heat of the sun acts as before, and the sunken water returns to the surface, bringing with it as much *reh* as it can hold in solution, and leaves it, as it did the first time, in a state of efflorescence. After some months a shower of rain falls, and the process described before is repeated. This process occurs always once every year, and sometimes more than once every year. But there must in every instance be a sufficient interval between two periods of rainfall to allow of the evaporation of moisture, and the efflorescence of *reh* in sufficient quantity to befoul the drainage resulting from the second rainfall

With every repetition an accession of *reh* is received by *ab*, *cd*, *ef*, from *bc*, *de*, *fg*, until the final condition of the ~~tract~~ may be represented by the diagram (*Fig.* 112, *Plate* X).—

It is true that a small quantity of *reh* may be constantly carried horizontally by subsoil percolation from A and C into B, from C and E into D, etc, but it is all brought to the surfaces *bc*, *de*, *fg*, eventually by evaporation, and is again washed into *ab*, *cd*, *ef*, and thence into A, C, E.

The amount therefore cannot increase in B, D, F, as whatever *reh* is introduced into them by subsoil percolation is returned to A, C, and F by circulation.

I have supposed the height of the elevations *bc, de, fg*, to be 2 or 3 inches. This is of course an arbitrary height The height really required to preserve *bc, &c*, entirely from *reh* is such a height as is necessary to prevent *reh*-polluted water from resting over and sinking into them. Two or three inches are generally sufficient

It will now be understood that the chief agent in the distribution of *reh* is the water which travels over the surface of the ground after the first fall of rain which succeeds a period of sunshine. I will denominate the action of this water "early surface drainage," in distinction to the "late surface drainage" which is carried along deeper and generally very different drainage lines The depressions in the surface which catch and hold *reh* may be appropriately termed "*reh*-traps"

A familiar illustration of the distribution of *reh* by the above process is an *usar* plain itself. No one who walks in the hot weather over an *usar* (*i. e* *reh*-infected) plain on which grass is growing, can avoid being struck by the alternation of small, irregularly-shaped green and white, or rather brown-and-white patches (for by the time the sun has whitened the patches of *reh*, it has browned the patches of grass) A very little examination will show that the brown grass patches are higher than the white *reh* patches, the reason being that less *reh* water settles in the higher than in the lower patches. The area of the patches is often only a few square inches, and their height not more than half an inch

A similar distribution may frequently be observed on a larger scale where the cultivated fields of an *usar* plain occupy slightly elevated levels

Of the following diagrams (*Plate* X) —

Fig 113 shows the alternation of *reh*-infected tracts with tracts not infected with *reh* in an area of 136 square miles of a pargana of the Cawnpore district, Scale—3 miles to the inch.

Fig 114 shows the alternation of cultivated and uncultivated land on 615 acres of a *reh*-infected tract, Scale—½ mile to the inch

Fig. 115 shows the alternation of grass and *reh* patches on 15 square yards of an *usar* plain, Scale—3 feet in the inch.

Fig 114 is a magnified illustration of the yellow or *reh*-infected portions of a tract similar to that represented by *Fig.* 113 *Fig* 115 is a highly magnified specimen of the yellow or *reh*-infected portions of a tract similar to that represented by *Fig.* 114. There is a strong family likeness in these three diagrams, and so there should be, for the distribution of *reh* is due in each case to the same cause, *viz*, the erosive action of surface drainage which gives rise to shapes of a somewhat fantastic character *

But other causes than drainage may operate to elevate one portion of a surface above another. The dust blown along by the wind over an *usar* plain will lodge against a bush, and with the falling leaves will gradually form a little elevated heap at its foot, seeds will drop in the heap, other bushes will spring up, and gradually the elevation will push itself round the original bush over the *reh*-infected soil. *Reh* will of course be brought up from below through the layer of leaves and dust by evaporation, but it will be washed off the surface to the lower levels by the first shower of rain In this way a gradually extending elevation is formed, which is, like *bc, de, fg* of our illustration, free from *reh*.

* Note —One officer remarks that he has no theory to bring forward regarding the question "why are *usar* and *reh* where they are?" The cropping up of *reh* in odd fantastic patches is, he says, no more ultimately explicable to one's mind than the fantastic shapes of continents and peninsulas But are not both partly due to the same cause,—The erosive action of drainage?

Mr Smeaton says:—"The idea of the cultivator seems to be that if by digging sufficiently deep, and hitting happily on a favourable spot less impregnated than the surrounding lands, he can get a tree (mango or *mahua*) to take a grip of the soil, he has raised an effectual barrier to the encroachment of *reh*, as far as the shadow of the tree extends, and that, further, the saline impregnations all round will gradually be neutralized, till finally the soil becomes fit for cultivation."

This result *may* be partly due to the absorption of *reh* by the tree itself, but I suspect that the *debris* of leaves and dust under the tree is the chief cause of the removal of the *reh*, (1), because I have seen mangoes killed by *reh*, (2), because *reh* cannot rest on the surface of an elevation if a passage to a lower level is open, any more than an apple can rest without support in the air

Mr. J. Knight says —"The culturable patches of land in the middle of *usar* are the parts of the lands which have not succumbed to the *reh*, or are spots where the wild plum or *jarbari* has taken root and has flourished for years, gradually attracting to itself cattle, and holding in its close roots and small leaves the wind-borne dust of years, until in course of time the spot is raised higher by 6 to 10 inches above the surrounding country It is these spots the cultivator often breaks up for a small *jauri* crop of fodder"

There are, no doubt, some trees and bushes which absorb *reh* and grow well in a *reh*-infected soil if the *reh* is not excessive. Such is the common *dhák* But the diminution of *reh* in their immediate vicinity is probably due more to the action of surface drainage than to absorption by the shrubs I have noticed many cases of the beneficial effect of shrubs and trees in an *usar* plain, and have found that the extent of good soil in their vicinity (strongly marked by the growth of grass) is more commensurate with their "bushiness" than with their size, by which their power of suction must be measured.

To return again to our illustratory diagram (*Fig* 116, *Plate* XI) Let *a....g* instead of being level be an incline, with the same shallow depressions *ab, cd, ef* as before.

Let D a ditch be dug at the lower end. Will the ditch carry off the *reh* of the land *d........ .g*? It will not, if the elevations *bc, de* are sufficiently high to prevent the early surface drainage from passing to D. A later drainage flow, such as S S, although rising above *bc, de, fg*, is ineffectual to carry off the *reh* which has been locked up below *ab, cd, ef*, by the early surface drainage I have met with several cases which demonstrate this fact. The following is one —

At Aima, a village in the Farrukhabad district, the canal road is built up of earth largely impregnated with *reh*, and as the road rises at this point up to a high bridge, a considerable quantity of *reh* is thus collected.

Every year the rains wash from the road a large amount of *reh*, which is carried about by the early surface drainage in every direction to which it has access.

Unfortunately, within a very short distance of the *reh*-constructed road lies a large tract of rice fields, each of which is surrounded, according to the custom of this part of the country, by a miniature bank about two or three inches high.

The shallow *reh*-bearing drainage water of the early rains attacks this rice tract. Wherever the two or three-inch high barrier is unbroken, the *reh* water is excluded, but wherever a breach exists, even if it is only two or three inches wide, there the *reh* water effects an entrance and pushes along across the field, sometimes spreading over it in a broad stream, sometimes meandering across it in a narrow line, until it reaches the

opposite bank, through which, if there be ever so small an opening, it takes the opportunity of passing into the field beyond. As the stream proceeds, it leaves a tract of *reh*, which when blanched by the evaporating heat of the sun marks its course as if with paint.

The diagram (*Fig.* 117, *Plate* XI) illustrates the way in which *reh* has penetrated into the rice tract, and gives a clear example of the action of early shallow surface drainage, and of the ineffectiveness of late deep surface drainage in the removal of *reh*.

Let A denote the bank built up of *reh* earth, R R the stream of *reh* washed off it and spreading in the direction of the arrows.

Let BCDE be a portion of the rice tract, and let *r r* be one of the meandering streams of *reh* which has found its way into the rice tracts through narrow openings in the field boundaries, *abcd* represents the field which terminates its course. The field slopes from left to right and the *reh* stream which had been going from right to left is reversed, and travels across the field to the corner *bdc*, which is the lowest in the field, leaving the shaded and higher portions untouched. The banks *bd*, *dc* are only 3 inches high, and yet serve to keep *reh* completely out of F and G, notwithstanding that late in the season the whole tract is *covered with water to a depth of two or three feet* which flows off from *right to left*. Nothing can show more clearly than this case that the *reh* has been removed by the early drainage, and is untouched by the later drainage. In this instance the *reh* had only begun to appear within the last few years in the rice fields.

The natural drainage of the deeper water has been assisted by a ditch DE, which has been dug in the centre of the rice tract with the object of draining off the *reh*; but the early surface drainage cannot get into it, and the ditch is therefore ineffectual. This fact shows clearly that if it desired to drain off *reh*, care must be taken to guide the drainage which comes into contact with *reh*, and not the drainage which does not come into contact with *reh*. This fact alone then shows how misleading is the general assertion that drainage removes *reh*, and how large sums of money might be spent in improving the deep drainage lines without having the smallest effect in the removal of *reh*.

I now pass from the horizontal to the vertical distribution of *reh*.

Depth of reh below surface varies.—One of the points brought out by the questions and replies on *reh* and *usar* is, that *reh* is found to reach varying depths.

There are two reasons why it should be so. (1), *reh* in solution cannot remain in sand, and is, therefore, carried off when it reaches a sandy substratum. (2) it is accumulated in less quantities in some places than in others, and is, therefore, found at less depths in some places than in others.

All the Settlement Officers of *reh* districts testify in their replies that "*reh* is never found in sand."

The following is an instance in point from my note book:—

AB, CD is an unculturable *usar* plain, across which runs a strip of cultivated land of considerable length, but only four or five yards wide. This strip contains sandy soil, and is perfectly free from *reh*. The *usar* plain on each side contains loam and is saturated with *reh*. On digging into the *reh*-infected loam at 40 paces from the edge of the field, the sand stratum was reached at a depth of five or six inches, and was again found free of *reh* as represented in the diagrams (*Figs.* 118 and 119, *Plate* XI):—

ABE, DCG represent the *reh*-infected loam, EFG, the pure sand with a crop growing at F between BC.

During my tour in the Farrukhabad district, I had specimens of soil brought up daily from one or two earthen wells in the vicinity of my camp, earth being taken from the sides of the wells at intervals of two or three feet. In this way some hundreds of wells were examined and as many of them were constructed in *usar* plains outside cultivated tracts, I can speak with some authority on the subject of the vertical depth of *reh* I never found *reh* in sand. In loam I found it at varying depths, sometimes reaching to the water level, but generally descending only two or three feet, and often less It aways increased in quantity towards the surface, for which circumstance the evaporating process is sufficient to account

The diagram (*Fig* 120, *Plate* XI) may explain why *reh* is found at different depths in different places :—

Let AB be a sloping stretch of *reh*-infected country, BC in check in a slope.

If BC is inclined upwards, or if there is a bank at C, (as CD,) it follows that the *reh* washed down AB cannot escape down DE, but must be lodged in BC, by the early surface drainage, BC becomes what I will call a *reh*-trap, and the only limit to the quantity of *reh* deposited in it is the exhaustion of the supply in AB From what has been said before it is obvious that an obstruction at C of a few inches in height is sufficient to stop the progress of the *reh* and convert BC into a *reh*-trap, which catches and holds securely all the salts brought down year after year by the drainage of AB

The depth of *reh* at BC will then vary according to the extent of AB, and the amount of *reh* supplied by it

Again, let BC be level, or even slightly inclining towards from left to right and without obstruction as before at C (*Fig* 121, *Plate* XI).

The surface of BC not being smooth like glass, still checks and absorbs some of the surface drainage from AB, and especially the surface drainage of the early rains, when the ground is dry and thirsty and sucks in moisture readily, at the same time it parts with some, though perhaps very little, of its early surface drainage to CD. BC will probably become an *usar* plain, though the amount of *reh* in its soil will be considerably less than it would be if there were an obstruction at C, as in the last case.

Collection of reh in drainage catch basins —It may now be readily understood that a favourite locality for *usar* plains is the level floor of what Engineers call "a drainage catch basin." Their position may be represented roughly by the diagram (*Fig.* 122, *Plate* XI).—

ABEF is the sloping country, BC, DE, are *usar* plains, *g*G is the drainage flow down the centre of the catch-basin at right angles to BC, DE

It generally happens that on each side of a drainage flow a tract of alluvial and culturable soil is formed, very often of considerable extent (as represented by *c*C, *d*D in *Fig* 122 *Plate* XI)

The explanation is simple. Sometimes the *reh*-bearing water which reaches the middle of the basin is carried down the centre drainage line at once by a strong scour, and sometimes, if there is no immediate scour, it is held above the alluvial clay (which it cannot easily penetrate) until the water reaches a sufficient height to enable the drainage flow to carry it off. Sometimes, however, the presence of *reh* is manifest even in a clay bed, in which case the bed is usually shallow, with less opportunity of

collecting alluvial clay than of collecting saline solutions, and sometimes *reh* may be observed in certain patches of a pond or *jhil* which will produce nothing but rank grass *

Reh absent from highest and lowest levels.—But as a rule *reh* does not collect at the bottom of a deep drainage line, and we have, therefore, presented to our view the apparent incongruity of the highest and lowest levels being at once free from *reh*.

In reality there is no incongruity. Both the highest and lowest levels are those from which the *reh* is most easily washed. It is only those places which catch the surface drainage in its passage from the higher to the lower levels which retain *reh*. Mr. Crosthwaite, Settlement officer of Etawah, a district full of *usar* plains and *reh*-infected land, illustrates concisely the process which occurs by his observation that "he could recognize no general physical law in *reh* lands, except that they do not allow water to drain freely downwards, and are level"

Formation of dumat *or loam, and* mutyar *or clay tracts due to drainage*—The formation of loam (*dumat*) and clay (*mutyar*) tracts is due, like the distribution of *reh*, to the action of superficial drainage

A short description of the physical character of that part of the *doáb* with which I am acquainted will not be out of place.

The main stratum of the country is a light soil containing a good deal of silica. It is intersected by a succession of small rivers, more or less parallel, which flow in a slanting direction into the great rivers the Ganges and the Jumna They are usually flanked on each side by an undulating strip of varying width which the drainage has cut up and rendered sandy. But between each pair of rivers, and skirted by the sandy strips, is a depressed table land of some few miles in width in which the soil is principally *dumat*, and which is full of lakes or *jhils* and *reh*-infected tracts Sometimes, as I proved by the persistent examination of earthen wells over a tract 400 or 500 square miles in extent, the *dumat* stratum is very shallow, a mere veneer as it were above the more sandy stratum, and somtimes it disappears entirely or alternates with patches of sand.

Dumat tracts are less interrupted by sandy tracts, and the soil is of a more and more consistent and impermeable character towards the lower parts of the sides of the catch-basins The strongest and richest soil, more and more like clay, is found as the bottom of the basin is approached

It follows that as *reh* is also carried towards the deeper levels, and is caught and retained in them wherever there is a *reh*-trap, it often happens that the worst *reh* soil is found side by side with the best and most fertile tracts.

I have now some evidence to offer on the influence of the canal with regard to the distribution of *reh* In the course of my duties as Settlement Officer, I had, as I have previously stated, occasion to inspect the country on either side of the Ganges Canal for some distance (about 30 miles of which were in the Farrukhabad district)

The canal passes for the whole distance along the centre of a depressed *dumat* water-shed lying between parallel rivers, and comes, therefore, constantly into contact with *usar* plains

* The alluvial soil affords sufficient nourishment and strength to the grass to enable it also to absorb the salts, which when mixed with other soil, even in considerable proportion, are actually beneficial to the growth of some species of rank grass.

I made special enquiries in every village whether the canal had impaired the fertility of cultivated land by the introduction of *reh* In the Farrukhabad district *I only found two cases along the whole* 30 *miles* where any marked effect had been produced.

The first of these was at Aima (noticed above) The canal here passes through a great natural *reh* pit, the *reh* being very deep and plentiful on both sides

In the centre of the *reh* pit is built up a steeply-inclined road leading to a high bridge over the canal. The rain falling on this washes the *reh* which it contains over the rice *jhil* below it But not a single field is injured which is protected from the early surface drainage by an unbroken bank 2 or 3 inches high, and I can safely say that if a low wall 4 inches in height had been constructed round the rice tract, with a shallow ditch outside it, not a particle of *reh* would ever have penetrated into it I examined almost every injured field, and traced in every case the course of the small drainage stream, which had worked its way into it through a succession of breaches in the banks of surrounding fields.

The process which had been going on was curiously illustrated in miniature by a *sujji* or soap factory which had been erected opposite the canal bank. The soap-maker, taking advantage of the accumulation of *reh* which the canal bank was furnishing, had built up, according to the practice of his trade, a heap of rubble and sticks, on which he placed *reh* scraped from the surface of the ground, the heap was flanked with two low mud walls leading to a large shallow reservoir of masonry surrounded by an edge of 2 or 3 inches high. He then poured water on the *reh* heap, the water taking up the *reh* in solution flowed into the reservoir, and there evaporating, left the *reh* in crystals behind When the soapmaker wanted more crystals he built up his heap again, put on more *reh* and poured more water. So, too, the canal workmen, finding their *reh* bank constantly washed down, were continually building it up with a new supply of *reh* earth, and thereby were continually affording a fresh fund of *reh* to be washed by the next rainfall over the rice fields

It has been frequently suggested that canal water filtering in a horizontal direction under ground, subsequently brings *reh* with it in an upward vertical direction to the surface under the influence of evaporation.

If so, such action is very slow There is no doubt that the vicinity of the canal increases the surface accumulation of *reh* on land where *reh* exists But facts show that it acts very slowly as an agent in carrying *reh* from the subsoil of a *reh*-infected tract into the subsoil of a sound piece of land, and thence by the evaporating process to the surface.

In the centre of the worst part of the Aima *reh* pit, a few yards from the canal bank, are some cultivated patches I could discern no *reh* in their soil and the crops seemed to be very good (here and there was a patch of *reh*, but introduced always by surface drainage through openings in the bank to low parts of the fields), and yet these fertile patches were surrounded by soil so saturated with *reh*, that when I dug a small well close to one of the fields, I found the earth full of *reh* to the water's edge.

I should be sorry to say that no *reh* is introduced under a sound piece of soil by the horizontal motion of subsoil infiltration, and thence by evaporation to the surface, but the circumstances which I have detailed show that the process, if it ever takes place, is a very slow one, even close to the canal bank, in a place where *reh* distinctly reaches to the water level.

It must be, then, very slow indeed where the land is at any reasonable distance from the canal, and where *reh* does not reach any considerable depth. The fact is that soil which holds *reh* is necessarily soil which is not easily permeated by water. If it were, *reh* would not rest in it, but be removed vertically downwards by subsoil filtration as fast as it came, just as is actually the case in all sandy strata

Even when *reh* is brought to the surface, it must generally be washed off again by the process described, since cultivated patches surrounded by *reh* soil are (except in the bottom of drainage flows) higher than the surrounding land

The next case to which I have alluded demonstrates still more clearly that subsoil percolation has produced no visible effect in a locality where the circumstances appeared to be most favourable to its action, and where the land has been exposed to its influence for years. In that case cultivated land was lying close to the canal bank. It was surrounded by *reh* and *usar* The fields bore numerous signs of *reh* having effected an inroad. At a first glance any observer would have said—"Here is a tract of land destroyed by the canal This is the effect of subsoil infiltration" But a close and detailed examination, extending over three or four days, proved conclusively that the inroad of *reh* was in every single instance due to early surface drainage having effected breaches through the field banks, the canal was guilty only so far that it had altered the direction of surface drainage The following diagrams (*Figs* 123 and 124, *Plate* XI) are copies of some sketches which were made on the spot The arrows show the slope of the ground, the shaded portions denote standing crops, the dotted portion *reh*.

In *Fig* 123 it will be observed that the field *xyz* is totally destroyed by *reh*. When I told the cultivators that if they closed the breaches in the banks of their fields they could keep *reh* out of them, they pointed to *xyz* and said—"Here is a field higher than the *usar* plain, how then could a bank keep out the *reh*?" They were right, it was higher. but they themselves had constructed a bank higher than the field *built up of reh earth from the usar plain.* This had washed over the field and destroyed it, and the *reh* thus brought upon it was now forcing its way out of it through three breaches in a low bank into the adjoining field *wst* Into *pqr* it had come along a narrow ditch *yzs*; into other fields breaches in the through banks, into *mnpj* through another field But in the midst of all these fields the field B was untouched, and yet in the rains stagnant water, communicating with the *usar* plain, covered the whole of the fields and *was deepest in* B.

Early surface drainage therefore was again the introducing agent. Neither later inundations nor subsoil percolation from the canal had exercised the slightest influence on the distribution of *reh*. The presence of the canal affected it only in so far that it had changed the direction of surface drainage by cutting across and diverting a natural drainage line, which it caused to attack the neighbouring tracts of cultivation

The course of the *reh* stream from M is marked in *Fig* 124 by dotted paths, but on the ground the paths were not completely bare for their whole length In some places crops were growing. These were, however, always very stunted, and by their shortness showed plainly the course of the *reh*, but wherever there was a slight hollow which acted as a *reh*-trap, the path was quite bare.

In *Fig* 124 the effect of low banks in checking the further progress of *reh* is well marked CD is a very small bank, and yet quite stops the *reh*, which has travelled all the way from M, from going into ABCD

ABCD is, however, almost completely destroyed by *reh*, but the *reh*, has not come *viâ* CD. It has got in from *usar* plain by breaches in AC, and has covered all the field except a little patch higher than the rest which lies close under the left side of CD

These facts clearly demonstrate the active influence of early surface drainage introducing *reh*, other facts show just as strongly the absence of the action of subsoil percolation. For instance, the *usar* plain and fields of *Fig* 124 are perfectly saturated with stagnant water in the rains. The water-tank marks the point where the drainage of several miles of country used to cross the canal from south to north. The main part of the drainage is now diverted to the south by a cut dug by the Canal Engineers, but it can be easily understood that the drainage of a small area round this point does not escape along this cut, but rests against the canal bank in a vain endeavour to get away at the point where the drainage used to cross the canal.

The effect of this accumulation of water, most of which comes from the *usar* plain, is that efflorescent *reh* is continually being washed into the water-tank, whence it has no exit, and is now accumulated in such quantities that it quite discolours the water.

Now the fields in *Fig* 124 are flanked on one side by the canal and on the other by the foul water tank, and yet they are to all appearance unimpaired, except by *reh*, which has been carried into them from a totally different direction by the action of surface drainage

No case can be conceived in which sub-soil percolation had a better opportunity for action.

Here is cultivated land swamped with floods in the rains, the canal running along one side, and a deep pool full of *reh* stagnating on another side, and yet the action of sub-soil percolation is so slight that, although it has had the whole period since the canal was constructed in which to act, its effect is imperceptible. It may have caused a diminution of produce, but it has certainly not destroyed cultivation.

Let that little patch of corn at CD bear evidence. There it is exposed to the full influence of sub-soil percolation, and yet it flourishes, and has escaped destruction, solely because it is protected by a low barrier from the early *reh*-bearing surface drainage of the first rains That small plot of wheat is worth any amount of written speculation.

I have now described the only two cases in which, throughout 50 miles of its course along a *reh*-infected country, the Ganges Canal has affected cultivation to any appreciable extent In both those cases the damage has been traced conclusively to the action of early surface drainage No perceptible injury can be attributed along the whole of this tract to the influence of subsoil percolation It must be remembered that my examination of this tract was no cursory one I examined every part of each village, and no case could possibly have escaped my notice. Since examining this tract of country, I have inspected another 15 miles of the canal through an equally *reh*-infected tract The canal water-courses have been constructed in this tract at right angles to the drainage courses, and have diverted or obstructed the natural drainage flow in many places, and thereby caused *reh* to appear in many new localities. In every case the appearance of *reh* can be traced to the action of surface drainage

I consider that the above facts, collected carefully along 45 miles of the Ganges Canal in its passage through an *usar* country, prove conclusively that the enemy which we have to attack is early surface drainage, and not subsoil percolation. It is however, an enemy which, when we have once defeated, we can turn into a most useful friend.

Before leaving the subject of the connection of the canal with the distribution of *reh*, I wish to bring to notice one way in which *reh* is often introduced into fields by the cultivators themselves through the agency of canal water—and entirely on the early surface drainage principle.

Canal water-ducts (*guls*) are frequently constructed over *usar* plains, the more frequently that they may not cut up good land Whenever one of these ducts has been used for irrigation, and exposed subsequently to the sun, *reh* effloresces on the surface. The next time that water is brought along it, the efflorescent *reh* is taken up in solution and carried into the irrigated field. A bald patch soon appears at the mouth of the duct, and year by year extends further into the field. This circumstance is very likely to give the impression that canal water is injurious But the fault does not lie in the canal water The *reh* which has collected on the surface of the duct is the destroying agent. The remedy is easy Let the first gallon or two of water (the only water which has the opportunity of coming into contract with efflorescent *reh*) be turned into a small pit outside the field, and all subsequent water will pass over clean ground, and may safely be used for purposes of irrigation.

I will now again call attention to *Fig* 123, as illustrative of the way in which bald patches in fields are originally produced. They are, as may be inferred from what I have already said at so much length, nothing but *reh*-traps. But as I had in this instance the opportunity of witnessing as it were their manufacture, I will describe the facts which came under my notice.

One night in the cold weather a shower of rain of two or three hours' duration fell after a long period of sunny weather. I happened to visit the fields shown in *Fig.* 123 the next morning Every part of the fields was then dry except the small round patches figured in the diagram, in which there was about enough water to cover the flat land. These bald patches were gentle depressions in the surface, and therefore *reh*-traps. The cultivators told me these patches had only appeared during the last three or four years, and enquiry proved that the breaches in the banks admitting water from the *usar* plain into them had only occurred within the same period.

Here, then, was early surface drainage carrying efflorescent *reh* into shallow depressions, and converting them into barren spots before my very eyes. Bald patches, however, are not usually produced in a field *after* it is brought under cultivation. They have been depressions in the *usar* plain, in which *reh* accumulated before the land was brought under cultivation, and as it is not possible that they can ever part with the *reh* so accumulated as long as their surface is not raised higher (even though they be ploughed) than that of the surrounding field, they always remain bare spots.

There is another point connected with the fields of *Fig.* 123 which is worth noticing The course of the *reh* streams from the breaches in the bank to the bald patches was not always completely bare of crops It was generally, indeed, marked by a line of stunted growth, interrupted by a bare spot wherever there was sufficient depression to check the *reh* The worst bald patches were those in which the stream terminated, and while efflorescence was considerable in them, no efflorescence was apparent along any part of the *reh* path. This is an illustration, on a small scale, of the explanation which I have already given, why unequal quantities of *reh* are found in different places.

The absence of efflorescence was simply due to there being less *reh*, as well as less evaporation, in the *reh* path than in the baldi patches Many *usar* plains exist in a *reh*-infected tract which has no apparent efflorescence. These are plains in which less water stagnates and less *reh* accumulates than in the efflorescent plains. They are often like the paths of stunted crops, merely ground over which *reh*-infected water travels, and not places where it accumulates

But it generally happens that a film of efflorescent *reh* which may be readily taken up on the blade of a knife, really lies on the surface even of *usar* plains in which no efflorescence is apparent to the eye of a person walking across it. I have often found this the case in the hot weather. It is not safe, therefore, to suppose that *usar* plains do not owe their barrenness to *reh* because efflorescent *reh* is not perceptible to the eye. A considerable amount both of evaporation and of *reh* is required to produce efflorescence of a conspicuous character. "*Usar*" is doubtless a generic term for barren land, but throughout the *dumat* drainage basins of the lower *doáb*, *usar* plains owe their barrenness entirely to the presence of salts which would effloresce If present in sufficient quantity, and if aided by a sufficient amount of moisture

I have only a few words to say as to the method in which *reh* should be eliminated. I do not wish to go at any length into this subject, as I have at present had no opportunity of making any experiment My chief object is to illustrate by a carefully collected series of facts the natural process by which *reh* is distributed, and merely to indicate that the reclamation of *reh*-infected land must be effected by imitating the action of nature

Only one method of cultivating *reh* land is to form an enclosure round a plot of ground, remove the top crust (in which *reh* is most dense) by mechanical means, and then fill the enclosure with water, and keep it full of water while a crop of rice is being grown

The water of course keeps the *reh* in solution underground for the time But when the moisture dries up the *reh* rises again to the surface, and, as we are told, prevents anything but rice being grown The expedient is, therefore, but a temporary device.

The permanent removal of *reh* is the object to be attained. Water is doubtless the most natural, and probably the cheapest, agent by which it can be effected

The process of removal by the agency of water must consist of three stages.—

(i) The moistening of *reh* soil.

(ii) The evaporation by which *reh* is brought to the surface in efflorescence.

(iii) The washing of efflorescent *reh* from the surface.

The first two stages are accomplished every year at and after each rain, and they may be repeated constantly with the aid of canal water, where it is available at a proper level, but the third step is not so easy. One of the chief lessons to be learned from the facts which have been collected is, that the washing of *reh* from a surface must be rapidly effected. There must be no level or depressed areas in the surface, otherwise they will act as *reh*-traps.

An *usar* plain is in fact infected by *reh*, because shallow drainage water does not run off its surface easily. It is, therefore, necessary to manipulate its surface so that water may run off easily It is possible that if broad ridges and furrows were constructed, the ridges might eventually become culturable, and the furrows

full of *reh*. If at the same time the furrows were well seconded by a flush of water, both ridges and furrows might become cleansed of *reh*. The surface soil would, at the same time, lose some part of its fertilizing elements, which would have to be replaced by manure.

This process might certainly be tried where canal water is available at a suitable level.

The assistance of shrubs, etc., might be employed by planting them along the ridges, as soon as they were sufficiently free from *reh* to allow the shrubs to take root.

The formation of ridges or elevations, and the fertilization of them with manure, is exactly the process by which shrubs create fertile patches in their vicinity, the dropping of leaves and intercepted dust create an elevation which they at the same time fertilize.

The removal of *reh* to a deep drainage line or river is not at all necessary. It is quite sufficient to scour it into small wells or pits dug at intervals over the ground taken in hand, where it would be quite harmless, except to the area which the pits themselves occupied. This can be readily understood by the light of th facts which I have produced, and I am sure no one who has seen bad *usar* blotches close to good cultivation can venture to doubt it. All we have to do is to manufacture *reh*-traps and guide the surface drainage into them It must be borne in mind, however, that *reh* cannot be easily eradicated from a tract in which it has sunk to a great depth.

Experiments must determine whether the reclamation of *usar* plains can be effected profitably, and though I am glad to see that they are being tried elsewhere I have as yet had no opportunities to try them myself

I believe, however, that the facts which I have brought forward may be of some use—

(1) In determining the direction in which experiments should be made.

(2) In preventing the waste of money which might be laid out in attempting to remove *reh* by deep drainage lines

(3) In pointing out that the mischief which is occasionally caused by the canal may be completely prevented by properly manipulating surface drainage.

APPENDIX V.

ADMINISTRATION.

1. **General character of the Administration.**—When the construction of an Irrigation work is completed, it becomes to a great extent a commercial undertaking, the success of which is in great measure dependent on the perfection of the arrangements for its administration. It is doubly commercial because its transactions with the people should properly ensure both the land revenue, and produce a profit on the Capital expended at least equal to the gain that Capital would have earned if it had been safely invested otherwise. The Administration has, however, to deal with much more than merely the commercial side of the undertaking, it has to adjudicate on the people whose prosperity and very existence often are dependent on the operations it controls, while carrying out the provisions of the law, not in a rigid but in a just and equitable system.

In most of the great earning departments of the Government of India, the systems of administration now in vogue have gradually developed themselves so as to suit the needs of the business to be carried on, in very much the same manner as the special style of working of a commercial house or public company is built up, and the almost uniform success of these departments shows that this procedure is preferable to attempts to conform the working to any theoretical rules, however suitable they may appear at first sight.

From time to time the procedure shown necessary by experience is confirmed or modified by law or Government orders, and every person employed in these great departments can to some extent influence their advance in good work by a patient study of the details of the special branch in his immediate charge.

2. **Government.**—The Irrigation Department in India is governed by an Act of Council, and is controlled by an Inspector-General at the headquarters of Government and by Chief* or Superintending Engineers in each Province and Administration. The Chief Engineer, who is always Secretary to the Local Government for his Branch, is generally aided in details by Under and Assistant Secretaries, who are responsible that professional and official matters are correctly and properly brought before the Chief without unnecessary delay.

* The same officer occasionally controls both the Irrigation and Public Works Branches

3, **The Chief Engineer.**—The Administrative, Financial, and Executive powers of the Chief Engineer are clearly laid down by a Code of Rules and the orders of Government in general or special cases, and by Circulars published from time to time Each Local Department is divided into Circles of a certain number of Executive Divisions. The officers in charge of Circles are termed Superintending Engineers and have administrative and financial powers (under the Chief Engineer) clearly defined by Code rules.

4 **Tours**—Both Chief and Superintending Engineers must necessarily be officers of great experience in the details of Irrigation management, and they make tours of inspection to ensure that existing works are maintained in proper order, that the departmental rules are carefully observed, and to enquire on the spot into schemes of improvement or extension. These tours are also advantageous, as they enable personal acquaintance to be made with those serving under them by the officers who are responsible to Government and to their Establishments that a just system of promotion for merit is carried out.

5. **The Superintending Engineer**—The Superintending Engineer during his tours over the Divisions in his Circle, prepares inspection notes of the matters of interest he observes, for the information of the Chief Engineer, who is thus kept regularly acquainted with the condition and working of his Department. This officer is also able to introduce improvements in procedure or methods from his own experience, or from one Division to all the others, to regulate rates and qualities of work and efficiency of distribution of water, and in short to bring all the Divisions in his Circle to the proper standard

The establishment and management of Executive Divisions differs widely according to the system in force for the assessment of irrigation dues and the maintenance of works.

6. **System of Assessment.**—The system of assessment in the United Provinces includes a direct charge made for the water supplied according to the class of crops actually irrigated in the season, which is called the "occupier's rate," and a permanent increase in the revenue of the land considered as irrigable from the source of irrigation whether it is actually irrigated during the year or not. This latter rate is credited to the canal by a book transaction as enhanced land revenue, the amount being fixed by the responsible Civil officer during the progress of the periodical settlements of land revenue. When a new canal is irrigating land not previously settled for enhanced land revenue, this wet rate is

collected on land actually irrigated as the "owner's rate" until the next settlement is in force. The principles of assessment are practically the same in the United Provinces and the Punjab.

In the Punjab, occupier's rates are charged upon all canals except the Muzaffargarh Inundation canal. The rates vary according to the nature of the crop irrigated, and are assessed upon the area watered as determined by actual measurement.

An owner's rate may be charged in addition to the occupier's rate, provided this rate shall nowhere exceed the sum which, under the rules for the time being in force for the assessment of land revenue, might be assessed on such land on account of the increase in the annual value of produce thereof caused by the canals. Lands irrigated from wells or other sources besides canal, and assessed at irrigated rates at the settlement now in force, are excluded from the operation of owner's rate. On the Chenab Canal alone this rate is fixed at so much per acre or crop irrigated.

An owner's rate of this kind is levied only on the Western Jumna Canal, and is fixed at half the occupier's rate for the time being in force.

In the new colonies on the Chenab Canal an owner's rate of Re 1 per acre is leviable on all crops in addition to occupier's rate, but has been remitted for the first ten years succeeding the first admission to the occupancy, and is not therefore at present levied.

On other canals there is no owner's rate as defined in the Act, but a portion of the land revenue rate assessable on lands irrigated by the canals, is credited to the canals under the name of a water or canal-advantage rate, or of *nahri parta*. A water-advantage rate is assessable on the areas actually irrigated during the year in addition to the occupier's rate and is leviable on the Upper Sutlej Inundation Canals, the Lower Sohag and Para Canals, and the Shahpur Canals. The *nahri parta* is assessed on land recorded as canal-irrigated at the last settlement, whether actually irrigated or not during the year, and is realized on the Bari Doab and Swat River Canals. On the Sirhind Canal the only charge for irrigation is an occupier's rate. On the Muzaffargarh Canals there is no occupier's rate except for lands brought under irrigation since the last settlement. The canals are credited with a proportion of the land revenue assessment as fixed at last settlement, irrespective of the area actually irrigated from year to year.

Madras.—The water rates on the Madras Canals are collected by the Civil Department along with land revenue. The rates for water supplied to lands for irrigation vary according to the crops grown, and also according to the classifiation of the land under revisional settlement as " wet " or " dry. " In the case of " wet " land, it is assessed to a consolidated wet rate representing land revenue and water-rate, and this the ryot has to pay year in year out unless the land is left uncropped for want of water.

Sind—The system of assessments is the same as in the Madras Presidency. The water-rates are collected by the Civil officers along with the land revenue. Water-rates are charged on land according to the crops irrigated.

Bombay Presidency.—In Bombay, Deccan, water assessments are made by the Canal officers and collected by the Civil officers. The rates vary according to the crops irrigated.

Burma.—In Burma, assessments or irrigation and reclamation works are made and collected by the Civil Department There is only one Major Productive work in Burma which is nearing completion. The assessments proposed by the Local Government and accepted by the Government of India tentatively, subject to further consideration and report after three years' experience of their working, are—

(*a*) " Occupier's " rates for use of canal water varying according to the important varieties of crops raised.

(*b*) " Wet " land revenue rates on irrigated area under cultivation.

(*c*) " Dry " land revenue rates on unirrigated area under cultivation.

The difference between (*b*) and (*c*) to be a book credit to irrigation.

The canals in Bengal come under the class of unprofitable canals, because the country through which they run only requires water in exceptional years of drought. The water, therefore, has a comparatively small value, which can best be tested by the price which the cultivators are willing to pay for it The system of contracts, leases, and permits for irrigation is peculiar to this province.

It will be sufficient here to indicate the general system of management followed in the United Provinces, as it agrees in great measure with that of the Punjab. These are the provinces in which great systems of permanent canals have been most successfully worked, both as regards the prosperity of the people, and the financial success of the works. The

United Provinces system has generally to deal with more complicated conditions than those met with in the Punjab, where in many instances population and cultivation are wholly dependent on the canal, while in the United Provinces the canal water has frequently to be distributed with great care to avoid interference with other sources of permanent irrigation.

7. **The Executive Engineer.**—The Canal Division is the charge of the *Executive Engineer* whose functions are three-fold. He is responsible for the proper and economical construction and maintenance of all works, and should be alert to submit carefully-prepared proposals and estimates for improvements or extensions. This side of his duty also includes the control of the establishment, the finance, and the water allotted to his Division. Regarding all these matters, etc, he will be in constant communication with the Superintending Engineer, and with his Assistants but, except in the case of a very large work or an emergency, the Executive Engineer does not personally direct details, indeed this would be impossible, for to carry out his duties properly, it is necessary that he should move rapidly round his Division so as to keep in touch with all that goes on.

The Executive Engineer is also the chief Revenue and Judical authority of the Division, and his action in these most important functions is more controlled by regulations which it is his duty to interpret to the advantage of both the people and the Government than by the direct interference of superior officers.

The Executive Engineer is provided with an office establishment permanently situated at the headquarters of the Division in the direct charge of an Accountant, who must be a man of ability, experience, and character, as he has to carry out very onerous duties practically uncontrolled by the personal supervision of the Executive Engineer. The office work is subdivided into four branches, viz., Accounts, for the clerical correctness of which the Head Accountant is responsible; Drawing and Estimating under a Head Draftsman, English correspondence under a Head Clerk, and Vernacular work in the charge of a *Sarishtadár*, who always accompanies the Executive Engineer on tour, but who also checks the work of his assistants during halts at headquárters. As this office has to deal with expenditure often heavy, with the assessment and preparation of bills for dues frequently amounting to many lakhs of rupees, and with investigations of a very intricate nature, which have to be

accurately and rapidly made and carefully recorded for reference, it is of the highest importance that its working should be on a good system carried out methodically and promptly.

The Executive Engineer disposes of English office work on cases sent daily out to him prepared with all references, and has the vernacular correspondence read to him by the *Sarishtadar*, signing each paper on which an order is issued. He should be expert in the vernacular used, so as to be able to check the accuracy of the work of this important branch.

The correspondence of the Executive Engineer and the Divisional Staff generally, is carried on a special canal system by postal runners, and lines of canal on which there are important regulating gauges are provided with telegraph lines. The use of the Canal *dák** is open free to all persons wishing to correspond with the establishment on irrigation matters: this is necessary to give every facility for complaints against injustice or loss to the irrigating community—petitions of this nature are also exempted from Revenue stamps.

The Executive Engineer is always invested with magisterial powers for the purpose of initiating and trying cases of crime under the Canal Act, passing certain orders which require these powers, and to enable him to sign the warrants authorizing the Collectors of Districts to collect the Canal revenue.

The Executive Engineer is assisted by the officers in charge of Sub-Divisions and by a Deputy Magistrate As a rule all orders should be given through the officer in charge of the Sub-Division or work under inspection and not to his subordinates. When one of the latter is present and the former absent, the temptation to break this rule is often great but it is best adhered to, a contrary practice being decidedly subversive of discipline and good order; all orders should be clearly expressed in writing.

The Executive Engineer should constantly place himself in communication with *zamindars* and villagers unattended by the usual train of officials. Then and not until then will they fearlessly state their grievances. He should transact all business in the vernacular as publicly as possible, and be perfectly accessible at certain fixed hours every week-day.

8. **The Deputy Magistrate.**—The Deputy Magistrate is usually a native official promoted to this honourable position for integrity and good service in the Revenue branch. His duties are primarily judicial, and on him falls in great measure the trial of the law cases of the Division, but

* Postal line.

he is also responsible for the general accuracy of the Irrigation measurements; he should constantly be on the move, investigating the procedure of the Revenue establishment, correcting errors, training the new or inefficient hands, enquiring into cases of hardship, or injurious action of any kind. When the demand for water is strong he should assist in the distribution, and during the final measurements take a large share in the *partal* or check of the *Ziladar's* work in this direction. The Deputy Magistrate sends a daily diary of his movements, action, and opinions to the Executive Engineer, and ought to visit that officer frequently to personally explain his views on the points noted above.

The influence of an upright and active Deputy Magistrate in the Division cannot be overrated, both among the people and over the establishment junior to him. His cases are tried in the locality, often it may be on the very spot where the offence was committed. His rise from a junior position has made him so well acquainted with detail that he can with ease detect fraud and misrepresentation, which might deceive an officer of less experience, and his example and action will both promote a healthy tone amongst the lower-paid Government officials who are often exposed to great temptations.

9 **The Sub Divisional Officer.**—The Sub-Divisional officers usually are Assistant Engineers, but in some cases a specially selected Upper Subordinate is the right-hand man of the Executive Engineer. There may be two or more Sub-Divisions in each Division, and the senior officer is always liable to be called upon to act for the Executive Engineer, and should therefore be fully qualified for this position. Indeed it is proper for all officers to thus qualify themselves, as they cannot otherwise carry out their duties to the full extent desirable. Assistant Engineers when qualified are invested with magisterial powers, and manage their Sub-Divisions on very much the same systems as the Executive Engineer rules the Division, taking however, a large share in the actual execution of works. The Sub-Divisional officer is responsible for the measurements of all work done; of these he must keep a special record, and he has charge of all the stock of building materials, plant, etc. He submits in the first week of each month, detailed accounts of all manner of expenditure abstracted from a precise cash book, *in which he has entered all transactions with his own hand.* His office consists of an English Clerk and a Vernacular Writer, or *Munshi*, with a *peon* for messages and a guard in charge of a treasure chest. He is granted monthly credits on the Treasury in his Sub-Division on which he can draw, and all but petty payments are made by cheque.

The attention of a Sub-Divisional officer should be mainly devoted to the execution, check, and measurement of his works, the preparation of projects of improvement, the distribution of water, the check of irrigation measurements, and the instruction of his subordinates. The Executive Engineer should, therefore, relieve his assistants as far as possible from formal official work, conducting his correspondence by demi-official letters which can be returned noted when orders are carried out. It will, indeed, often be found practicable and judicious to have the Sub-Divisional monthly accounts written up in the head office from the cash-book sent in periodically for this purpose. This vernacular writer is indispensable, as work cannot be carried on properly without a daily disposal of this correspondence, which deals in minute detail with the current operations of the Sub-Division

Sub-Divisional officers are held responsible for the maintenance in working order, at a reasonable cost, of the works entrusted to them, for police arrangements, and for proper distribution of water. To enable them to check their expenditure on current repairs and original works, they are regularly kept informed of the sums allotted to each head by the Executive Engineer, and keep a register of expenditure written up monthly, and a rate book, corrected periodically by the results of experience The analysis of important rates should be frequently carried out and corrections made on the results of the labour actually employed on works in progress.

Except in the case of important construction and heavy supplies of material, regular contractors are not largely employed on running canals, the work generally required is scattered over a large area, often small in amount though requiring very accurate and quick execution: and it is therefore necessary for the Sub-Divisional officer to carefully maintain a number of petty contractors or task-workers, in order to ensure that his maintenance works are properly and economically carried out. He will best succeed in this by using fair rates, and making payments personally without delay on, as far as possible, his own measurements. It is very easy to ruin a petty contractor, or to destroy the efficiency of a Sub-Division, by an unreasonable strictness in adhering to rates fixed possibly without full knowledge of the circumstances, or by delays in settling disputes over petty points, but the savings made in this way will be found the worst possible economy in the long run. It is impossible to check daily labour when employed at isolated places, and the proper principle for all work is to fix a rate for its execution and pay promptly for it when properly done.

The Sub-Divisional officer should be personally acquainted with the principal *Zamindars* irrigating from the portion of canal in his charge, and with the character and capabilities of all his subordinates; he should not forget that it is his duty to instruct the junior hands, as well as to find fault with their action when wrong He should take every opportunity of verifying the accuracy of any irrigation measurements that may be going on in his vicinity, and not take it for granted, that when once his works are in good order, he need not often inspect them, than which there can be no greater mistake. They may be in admirable order, but constant inspection will do more to keep them so than many working parties. "The masters' eye is worth a dozen hands"

All works have, however, one common end, viz, efficient distribution of water, and for this the Sub-Divisional officer is the chief agent, and it should be his chief care

The establishment of a Sub-Division includes a *Zilladar* for revenue matters with *Amins* and *Patrols* for regulation, distribution, and measurement of water, working under him *Sub-Overseers* for construction and maintenance of works, with *Mistris* and *Mates* to assist them, and *Rangers* for the working and care of plantations. When navigation or large regulating works form part of the charge, the establishment includes *Tindals, Beldars, Mates,* etc The postal arrangements are also managed by the Sub Divisional officer

With the exception of *Mistris* and *Mates*, all these officials are held on the permanent list and are pensionable, and it is somewhat difficult to understand why the two classes mentioned should be treated differently, as they have to carry out important duties which require long training and special experience—are specialists and not at all easily recruited.

10. The Zilladar—A good *Zilladar* is a man whose importance cannot be overrated. He is the right hand of his superior in all matters connected with irrigation. He should know personally all the principal irrigators, and be known by almost every resident in his district, this being no bad test of his locomotion The *Zilladar's* principal duties are to control and measure the irrigation operations with the aid of the *Amins* and *Patrols*, and to collect the miscellaneous revenue. The warrants for this, as well as those for the irrigation rate, which is collected by the Civil authorities, should bear his, as well as the Executive Engineer's signature.

During his constant inspections the *Zilladar* enquires into the demand for water, the condition of the crops, and the efficiency of distributing channels; he investigates complaints of all kinds and measures up waste of water, reporting the cause and fixing the responsibility. His two great

cares are, that crops shall not be injured by want of an immediate detection of a sudden demand for water in any part of his district, and that the irrigation measurements may be correct and up to date. To promote efficiency in these respects he keeps up constant communication by letter with all his subordinates, and checks personally a large proportion of the measurements as they are made by the *Amins* and *Patrols*.

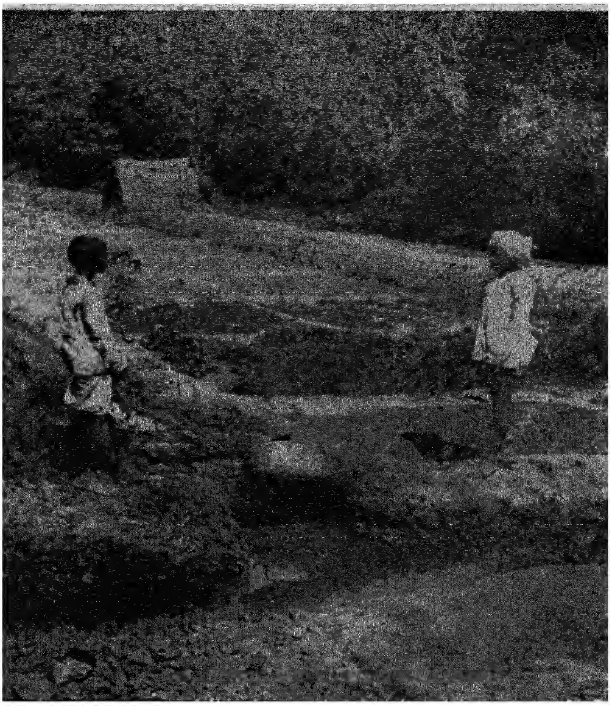
The *Zilladar*, though subordinate to the Sub-Divisional officer, corresponds directly with the Executive Engineer and Deputy Magistrate in certain cases, and he should never omit to send daily returns of all matters of interest in addition to the special reports of cases investigated.

Under the old system of designing irrigation channels the *Zilladar* among others had very heavy and responsible work thrown on his hands in connection with frequent re-arrangement of water-courses to suit demand. This necessitated in each instance a local investigation of the soils, the contours and the circumstances of the particular case under enquiry. Improvements in distribution were certainly carried out under this arrangement, but the general result was unsatisfactory, as it is bound to be when the main line is laid down before the water-course irrigating system is worked out in full detail. On new lines designed with the care shown as necessary in this Manual, the Sub-Divisional officer from his records will be able to supply the *Zilladar* with the minute particulars required for efficient distribution. The local investigation will be a thing of the past, and those changes in distributary alignments so disturbing and inconvenient to established village arrangements will be almost unknown.

The *Zilladar* is personally assisted by a *Muharrir* or clerk who keeps his records in order under his direction He is also supplied with a well-arranged office building where he assembles his staff, as the field measurement is completed, to work out the details of the rates. assessed. A bill of dues is made out for each cultivator and a copy handed to him before the originals, arranged into suitable groups (*Jamabandis,*) are despatched to the Civil authorities for collection.

Promotions to the important post of *Zilladar* are usually made from the *Amins* or Sub-Overseer class, men being selected of upright character, who have shown special ability in revenue matters. It would, however, be an advantage in the future to insist on a qualificati n in English, and provide a special training for *Amins* to fit them for this possible promotion.*

* The actual recovery from individual cultivators is made by certain of the village *Zamindars*, termed *Lambardars*, who receive a percentage for this responsibility and duty.



LIFT IRRIGATION-BALING FROM WATERCOURSE.

Photo.-etching, Roorkee College.

ZILLADAR AND PATROL RECORDING IRRIGATION.

In Divisions where distributing alignments have been laid down on a proper system and demarcated maps exist, the *Zilladars* should certainly be provided with copies of these records, as without them they cannot properly determine whether the water-course system is working efficiently or not They will be able to improve the maps by adding additional information as collected from time to time.

11. The Amin.—The duties of the *Amin* are simple though very laborious. Except when attending the *Zilladar's* office to collate his field work, he is daily out in his district, first checking the entries made by the *Patrol* in his *Shudkar*, or daily account of irrigation in progress, and afterwards when the irrigation has sufficiently progressed writing up his own final record He has also to assist in seeing that the cultivators irrigate in accordance with rules as far as concerns the avoidance of waste, and the correct division of the fields into compartments of a certain size, termed *kyaris* in the vernacular. *Kyaris* are always used for irrigation from wells, where water being necessarily expensive to raise, every means must be adopted to prevent the loss due to giving a greater depth than is necessary for the crops to any part of a field. With canal water charged for by the area irrigated and not by the quantity used, cultivators are often inclined to avoid the slight labour of making these temporary divisions in their fields, this results in waste, and where the field is very uneven, sometimes in a distinct injury to the crops from excessive damp. Except for actual measurements the *Amin* has no executive capacity, and his functions are limited to reporting irregularities to the *Zilladar*. When recording the irrigated area he is not allowed any discrimination, he must record *all* the area whether open to exemption or not. The decision in questionable cases must be given by competent authority in a recorded proceeding.

12. Complaints against measurements.—The proportion of complaints against measurements in each Division is annually revised by Government, and it is recognized that if the measurements are loyally and correctly carried out, a certain proportion of complaints must be made. An absence of complaints shows a lenient measurement, and possibly a fraudulent one, an excessive proportion may mean inefficient distribution or great carelessness in measuring In the millions of petty bills annually prepared errors must occur. but sufficient care and a proper system of check will keep these errors within reasonable bounds, and afford a ready and rapid means of correcting them when they do occur. It may here be said that, broadly speaking, the rapidity and accuracy with which the

irrigation bills in India are prepared and collected season after season, is very remarkable, and that alterations in a system so successful should be introduced with great care, and only by those intimately acquainted with the details of the working.

13. **The Patrol.**—An *Amin's* charge comprises the beats of a certain number of *patrols*, each of whom has the care of 5 to 8 miles of distributary channel with the irrigation done from that reach. His principal duties are to record the fields as they are irrigated in his *shudkar*, to regulate the supply entering the distributary head according to the orders in force, to make periodical reports of the readings of gauges in his charge, of demand, rainfall, and the condition of crops and works; he is often in direct charge of the petty repairs necessary for maintenance, and acts as postman when there is no regular *dák* line available. On channels still maintained on the old system of distribution he has to enforce internal *Tatils*, viz., temporary closure of all outlets in one or more sections of a distributary, to force a supply sufficient for irrigation to a section lower down. As this *Tatil* system is being steadily abandoned in favour of lines calculated to irrigate harmoniously throughout their whole length when open, it is unnecessary to dilate on its pernicious results, such as waste of water from heading-up, bursting of embankments and leakage in the closed lengths, temptation to breaches of rules by cultivators, and to condone and make a profit from the breaches by Patrols Indeed, with extensive *tatils*, the Patrol becomes the general manager of the irrigation in his tract, and a personage of authority and influence quite inconsistent with his nominal position. *Tatils* necessitate also constant inspections by superior officers, and a crop of law cases to be decided, all this distracting them from their more legitimate duties, with a result in satisfactory irrigation often quite inferior to the labour involved.

14. **Cattle trespass.**—The trespass of cattle on distributary banks is frequently the cause of friction between villagers and the canal petty establishment. It is the duty of the patrol to drive these cattle to the nearest pound when grazing is forbidden. But this always leads to quarrels, and as there is no advantage in preventing grazing except when channels are new and unconsolidated, it is much the simplest and most satisfactory procedure to auction the banks for grazing in short lengths, taking penal agreements from the lessees as to injury to the earthwork and trespass of cattle *in* the channel. This course is also economical as the annual jungle clearances will be lessened, and the grazing rights will fetch higher rates than those ordinarily given for cutting grass.

15. Patrol Schools.—It would be an advantage to start patrol schools for recruitment of the men required to keep up the establishment. There should be a preliminary entrance test in general education, and the training to be given in the school would then be only that necessary to fit the men for their special duties in the Department.

16 The Sub-Overseer.—The *Sub-Overseer* is chiefly employed as a purely executive official on survey and maintenance or construction of works, but he can be made a most valuable auxiliary in superintending irrigation. A good man will have much influence in his beat, and be looked up to by the community as second only to the *Zilladar*. The Sub-Overseer has charge of a section generally extending to about 12 miles of canal and 50 miles of distributaries with the dependent irrigation. He takes his orders from the Sub-Divisional officer.

The duties of the *Sub-Overseer* are multifarious, he may be called upon to perform nearly all the functions of the *Zilladar*. He has to survey, level, and draw plans, to take discharges, make measurements of work done, collect and pay labour parties, lay out and construct works, manufacture, and carry materials, keep accounts, and in short be able and ready to carry out promptly, efficiently, and economically all and any orders he may receive. He must constantly inspect his section, reporting all defects, correcting those within his authority, and applying for sanction when this is necessary. A great proportion of his work is scattered in small quantity over a large area, continuous personal supervision is therefore impracticable, and as he has only a mate or occasionally a *mistri* to assist him; he has to depend on good arrangement to ensure satisfactory execution. It will be evident from the above that a successful Sub-Overseer must be a well, educated man of ability and business capacity, and that he requires very careful training when first posted to a charge. This training is an important duty of the Engineer establishment, and if it is neglected, even the most promising young man, fully equipped by the Government Colleges with technical knowledge, will fail by drifting into slovenly business habits, and from ignorance of the proper methods of collecting labour and carrying out routine duties.

17. Possible improvements in the organization of establishment.—The arrangement of subordinate establishment briefly sketched above is that generally in vogue in the United Provinces. It will be observed that it involves two features which are capable of improvement: *First*, an imperfect system of maintenance under which it is very difficult for the Sub-Overseer to carry out his work efficiently, unless he has either

great personal influence in the district, which can only be secured by even the best men after long residence, or unless he utilizes the patrols for supervision of work, an employment for which they are unfitted, and which interferes with their more legitimate functions connected with irrigation. *Secondly*, a double measurement of irrigation effected, viz, originally by the Patrol in his *Shudkar*, which is checked by the *Amin* and the *Zilladar*, and finally an entirely fresh record by the *Amin* in his *khasra*, which is checked by the *Zilladar*, Deputy Magistrate, and Sub-Divisional officer.

The most efficient method of recording the irrigated area and providing for suitable and economical maintenance, would appear to be the combination of the irrigation functions of the *Amin* and Patrol in one official, and the introduction of a class of petty contractors for ordinary maintenance duties; these last to be paid a monthly wage as Government servants for charge of works, etc., and a suitable rate per mile of distributary to cover maintenance up to a fixed standard. Extra work such as silt-clearance, berm-cutting, etc., to be done by these men at the Divisional rates. This arrangement would save a great deal of accounting, release the Sub-Overseer from an unsuitable class of work, and provide an organization capable of mobilizing labour at any required place in cases of emergency.

The official combining the duties of both *Amin* and Patrol would be responsible for regulation and the record of irrigation only, entering up the area as watered once for all in a separate book for each water-course. The forms should be printed with the village names, and those field numbers only allotted for canal-irrigation on that particular water course, and it would be a great advantage to provide columns for showing the irrigation effected during at least three years on each page.

The simplicity and advantage of such a system will be recognised at once by those conversant with the details of the present vernacular records, *patral* or check will be very quickly and simply effected, and the collating of areas, *mauzawar*, i.e., by villages, reduced to a simple matter of copying. Every cultivator will receive a separate *parcha* or bill for the area he has irrigated from each water-course, and this can be given to him immediately the area is measured, which will be very shortly after it has been irrigated.

To the Canal officer desirous of knowing how his irrigation system is working the advantages are still greater. He can see at a glance the gradual increase or falling-off in irrigated area, and its exact locality over

a series of years; and this at any moment on his daily tour, without any complicated investigation or special enquiry; and he can at once detect unauthorized irrigation either in debarred fields, or across drainage outside the water-course specified limits.

Recently when discussing with an experienced Deputy Magistrate the improvements in the irrigation system introduced and comtemplated of late, this official, who had risen from the ranks, and was therefore well acquainted with matters, remarked that the abolition of *tatil* and remodelling when properly carried out, had already extinguished the patrol as far as his ancient functions were concerned, and that he feared there would be no good reason for keeping on Deputies in the future. I consider this naive expression of opinion the greatest praise that could be given in the way of efficient working

18. Rates.—The Executive Engineer should always carefully watch the working of the irrigation rates authorized for the canal under his charge. The considerations on which the Government of India fix the proper rates are too complicated and variable to be discussed in a Manual and it will be sufficient to state that it is with the direct or occupier's rate that the Executive Engineer has mostly to do, and if he is observant he can form opinions which may be very valuable at times to Government and the people.

It might be supposed that the lowest possible rate, or even free water if that could ever be supplied, would be advantageous to the people generally, but that this is not the case will be understood when it is borne in mind that water cannot be supplied everywhere. Indeed it can only be supplied to a very small percentage of the whole cultivating community, and there is no good reason why a small community which happens by accident to be suitably situated should be deliberately given extraordinary and unearned advantage over its neighbours. Nay more, such is human nature, if free or too cheap water was given, it would certainly be wasted and probably not valued. It is, therefore, expedient to charge a fair rate* merely on the principles of political economy. There are also agricultural reasons for charging correct rates; it is necessary for the general good of the country to keep a proper proportion between food-producing and commercial crops, and not to artificially stimulate the over-production of either beyond certain limits; nor is it good policy to induce over-cropping of the same land season after season, as this exhausts the land unless

*See Summary by Sir E. Buck, No. XXXIX, Canal Administration, Government of India.

the artificial manure supply is abundant. Now if the rate for irrigation of any crop is very low, an improvident cultivator may see his way to make small margins by frequent cropping and poor cultivation, and will seize this advantage particularly if he is a yearly tenant. The rates fixed should, therefore, be those calculated to encourage good cultivation without hampering it, and it is needless to add that their determination is a difficult and responsible undertaking.

APPENDIX VI.

IRRIGATION BY "KAREZ." *.

In countries like Baluchistan, Afghanistan, and Persia, which consist of more or less extensive alluvial plains, bounded by steep bare mountains, the amount of water in the rivers is generally speaking small, and the flow of water is not sufficiently constant to admit of the construction of large irrigation works.

Where such rivers occur small irrigation channels are made, and every means is taken by the cultivators to use the whole of the water in that way, but this does not provide water enough, or at suitable levels for the irrigation of all the culturable land.

Water is deposited on the ground from the sky either during very sharp thunder-storms in summer, or by rain or snow in the higher ground during winter.

The absence of vegetation or deep soil on the steep mountain sides prevents much of the water that falls in summer being retained: this water generally flows off very rapidly in violent floods, and in the case of Baluchistan, finds it way to the *pat*, † occasionally to the Indus on one side, to the streams draining into the Arabian Sea, or to the "Haman" of Seistan.

During the winter the rainfall is less violent, and more is absorbed, the snowfall on the higher hills also feeds the sub-soil as it slowly melts.

This process is assisted to some extent by the "*khuskkaba*" cultivation which prevails in the country.

The inhabitants are mostly nomadic. During the summer months they wander about grazing their flocks of sheep and goats in the upper region of the country, and whilst doing so prepare any suitable land on the higher plains or valleys for the retention of any rain or snow that may fall during the winter months.

They do this by making a series of earthen embankments across the valleys, ploughing up and sowing wheat or barley on the ground above each embankment.

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* By Lt-Col. E. Glenie, R E

† A vast alluvial plain.

These operations end about the time the increasing cold and exhaustion of the grazing obliges them to migrate to lower altitudes, and to leave nature to irrigate the land during their absence, the water being held up by the embankment and soaking into the ground.

The soils of these plains and valleys are composed of the detritus from the surrounding hills, and for want of a better term Mr. Oldham has in his paper on the Quetta sub-recent deposits, called by the name of "*Loess*" a special deposit overlying a permeable stratum of gravel, *see Fig* 1, *Plate* A. It stands to reason that the nearer the plain is to the hill-sides the more stony this deposit is, but as the plain recedes from the hills it becomes freer from boulders, and of a fine sandy nature, with occasional bands of clayey matter and a few "tongues" of boulder strata.

The rain water draining over this very friable deposit scours out deep *nalas* (known in Baluchistan under the name of "*Lora*"), the sides of which are vertical, and sometimes 70 to 90 feet high, and in the lower reaches the beds are water-logged and full of treacherous quicksands.

Although to the uninitiated eye these plains appear flat, such is not the case, the whole plain is tilted at a steep gradient, especially from the central *lora* across to the hills.

The rainfall or melting snow that is absorbed flows gently underground towards the *loras*, saturating the permeable strata, and it is for the object of tapping these reservoirs that *karezes* are made. (*See Fig.* 2, *Plate* A).

The surface slope of water in the saturated soil is greater than that of the plain, for the water tends to drain off to the *lora* at as low a point as possible. It is probable this gradient becomes steeper as the hill-side is approached, and the local configuration of the hills may tend to hold up the water near the hill-side, but in almost all cases the level of saturation at the junction of the hill with the plain is well below ground level.

The cultivators have to solve the question of where this saturated soil is to be met. In Baluchistan and Afghanistan they depend entirely on certain Ghilzais who have studied the point, and so possess considerable aptitude in determining the proximity or otherwise of these natural reservoirs. To a great extent they are guided by the presence of "*Chamans*" or large trees, but these indications do not always exist,

and no doubt they consider the geological stratification of the neighbouring cliffs and hill-sides.

Having decided on a likely place, the prospectors sink a vertical shaft about 3′ 5″ × 2′ 0″ until they reach the saturated subsoil ; into this they dig for a foot or so, then extend a tunnel up-stream as far as they can. If the soil is firm enough they sink one or more shafts up-stream 40 to 60 feet apart, and connect these shafts by tunnels dug in the saturated soil extending the tunnel up-stream as far as possible, so as to obtain extra surface for the infiltration of the water into the tunnel.

At the same time, however, as soon as water is found, the *karez* is extended down-stream, by making a line of shafts towards the land to be irrigated and connecting these by tunnels.

The proximity of the shafts to one another depends entirely on the cost of work and nature of the soil As a rule, 50 to 70 feet is the distance apart of the shafts, seldom more than 100 feet, and often as close as 40 feet.

The tunnels are made just sufficiently large for a man to work in, about 2′ × 3′ 6″, and do not require linings of any sort, indeed, the great expense of timber would make the cost of this prohibitive.

Shafts 70 feet deep are not unusual. To make the *karez* few implements are required, work is carried on by small gangs of Ghilzais, one man digging in the tunnel or shaft and filling a leather bucket which is drawn to the surface by a rough wooden windlass.

When the shaft is deep three or four men are employed at the windlass, and when the tunnel extends some distance from the shaft, one or two more men are employed to drag the bucket from the heading to the shaft and tie it on to the rope by which it is drawn to the surface.

The soil is heaped round the mouth of the shaft as a ready way to dispose of it, and also to prevent access into the shaft of drainage water.

The longitudinal slope of the *karez* when first constructed is made as great as possible to allow for its future reduction whenever this may become necessary for any reason. The Ghilzai determines this slope in a primitive manner by making a rough earthen channel on the surface from one shaft to the next one down-stream, and emptying a small amount of water into this channel. If the water flows along the channel from one shaft to the other, they accept the slope thus given to determine the depth of the lower shaft, but they take very few pains to grade the tunnel between the two shafts, leaving this to be done when the water is flowing through the *karez*.

In making a *karez* after it has left the saturated soil and entered the *loess* it is an advantage for it to have a clay bed. Occasional layers of clay are met with, but these may be thin and wavy, and piercing through such a layer in order to obtain a mathematically even bed may lead to the water in the *karez* disappearing into the soil below. It is, therefore, necessary in such work to pay careful attention to the technical knowledge possessed by the men brought up to the work, who, though otherwise ignorant and apparently stupid, are well acquainted with the practical details necessary for the successful attainment of their object in an economical manner.

The rates paid to these men near Quetta vary from Re. 0-5-0 to Re. 0-8-0 per foot of *karez* and shaft excavated; they expect besides to have the windlass, rope, and buckets provided free.

The rates at which they work depend on the depth of the shafts and nature of soil.

The *karez* when made requires constant care, and every year the channel has to be cleared of obstructions caused by the sides and roof falling in; in time large cavities are formed, and it may be that a new channel becomes necessary at some distance but parallel to the original *karez*.

The supply of water also diminishes after the *karez* has been used some time, the amount of the loss depending on the rainfall being sufficient or not to replenish the amount of water withdrawn. When the loss is serious the bed of the *karez* at its source has to be lowered or, if possible the tunnel has to be extended further into the saturated soil so as to continue to draw a sufficient quantity of water.

The following points are of importance in connection with the working of a *karez*:—

Under railway crossings the tunnel must be provided with masonry linings.

The Government of India have decided tha the cost of making such crossings for all existing *karez* is to be met by the Railway, and that should such a *karez* have to be deepened, the Railway department is to do so for that portion which passes under the railway. As this might lead to constant recurring expenses, the advisability of making such crossings at first as deep as may ever be required has to be considered, this can be done by means of syphons, but the cultivators are much opposed to this class of work.

Road crossings are subject to a similar ruling, but the light traffic common to Baluchistan roads does not affect the stability of a *karez* tunnel unless it is shallow.

When a lining is necessary a tube 2 feet in diameter made of corrugated iron is generally all that is required, but this prevents the *karez* being deepened. Another expedient is to bend corrugated iron sheet into an arch and fix it over the *karez*—this prevents the caving in of the roof of the *karez*. When the tunnel is over 30 feet below the surface, this allows of the bed being deepened by the cultivators.

It may be noted that heavy steam rollers and traction engines have passed constantly over unlined *karezes* in and about Quetta during the last 15 years without injury to the tunnels.

The principal object to keep in view when making a road or railway over a *karez* is to ensure that no flood water obtains access to the tunnel; if this happens an immense amount of damage may occur to the *karez*, and possibly some to the road or railway itself.

The description of the *karez* given in the Records of the Geological Survey of India, Volume XXV, Part, I, page 41, *et seq.*, by Mr. Oldham, gives much interesting information.

APPENDIX VII.

EXPERIMENTS MADE ON THE PASSAGE OF WATER THROUGH THE SAND OF THE CHENAB RIVER FROM THE KHANKI WEIR SITE—MAY, 1896.

BY LIEUT.-COLONEL J, CLIBBORN, I.S.C.

1. **Initiation and sanction.**—The experiments described in the following note have been carried out in accordance with the orders of the Government of India conveyed in their No 85I., dated 19th March, 1895. This letter placed a sum of Rs. 1,500 at my disposal for apparatus and experiments, and a further sum of Rs. 1,000 was supplied with Government of India No. 49 I., dated 7th March, 1896

2. **Apparatus employed.**—A plan of the apparatus with details as finally used is shown on *Plate* F. It includes a horizontal tube 120 feet long and 2 feet internal diameter, packed tightly with sand and supported on piers, a stand-pipe 20 feet high supplied with water from a cistern on the roof of the College, and a tail sand box fitted with a 5-foot drop curtain.

The level of water required for each experiment is maintained in the stand-pipe by means of a reducing valve fitted on the supply pipe between a stop valve and the stand-pipe. The correctness of the level is practically demonstrated to the observer by a float with indicator and by small stopcocks fitted into the stand-pipe at each foot, from which any small excess over the true level can escape.

The drop curtain can be brought into action when required by fixing a cover-plate on the opening of the sand box nearest to the tube, when this cover-plate is off, the water passes directly out of the tube and is discharged by a small pipe from the surface of the sand in the box; when the cover-plate is on, the water is forced down the sand under the drop curtain and up again through 5 feet of sand.

At 10-foot intervals along the tube are fitted man-holes with doors large enough to admit a boy, each door has a 2-inch screwed plug opening at the centre and a small discharging cock.

When an experiment is in progress, mercurial pressure gauges of the pattern shown in the plan above referred to are fitted to the screwed plug openings in the man-hole doors.

3 Objects of the experiments.—The objects of the experiments were to determine—

(i) the pressures transmitted by water under certain heads through sand at different distances from the heads;

(ii) the quantities of discharge of water through sand under different heads at different distances from the heads ;

(iii) the pressures capable of blowing sand through orifices ;

(iv) the useful effect of curtain walls.

This note records the experiments on Khanki sand alone—really useful results will be attained only after a series of experiments have been carried out on several other specimens of sands of different qualities.

4. Packing the tube with sand.—The tube was first filled with dry sand well settled by tapping the outside with wooden mallets, water was then admitted and the small settlement compensated for by careful ramming of the upper surface—although great care was taken, it was found that there was a minute separation of sand surface along the top of the tube ; through this a film of water passed quite vitiating the experiments.

Endeavours were made to fill up this very minute space first with water saturated with lime and afterwards with finely divided clay, forced in under pressure. This method of closing the space was not successful, the tamping material settled close to the orifice by which it was admitted, and it was not possible to increase the pressure without blowing the sand; and thus increasing the evil by the very means adopted to remedy it.

The tubes being fitted with man-holes at every 10 feet, it was only necessary to force the tamping material for 5 feet between the tube under-surface and the sand, but even this short length could not be properly filled ; a close examinntion also showed that the lime and clay permeated the sand downwards for some distance.

This method of closing cavities under masonry works has been recommended by some authorities, the experiment shows that it is not likely to be effectual with sands which can be moved by low velocities—it might answer with gravel or very coarse material.

Three inches in depth of sand was finally removed from the tube (*see* shaded portion in *Fig* 3, *Plate* B), and this space was packed with good puddle clay—the clay in the form and consistency of undried bricks was passed into the tube through the man-holes and very tightly rammed in 5-foot lengths from each end, the surface of the sand under the man-holes was left clear, the clay being taken round the edges,

This method proved quite satisfactory: it appears that the clay packing must swell slightly under pressure, and thus always keep the sand pressed against the sides of the tube.

When the experiments on Khanki sand were concluded, the sand was blown off from each man-hole orifice in turn, so as to form a clear water space, and the condition of the sand and clay packing was examined; it was found that the clay packing remained firmly attached to the sand below, and that there was a small space between the clay and the top of the tube which allowed clear water to pass to the orifice. These results are very interesting, as they show what a valuable material puddle is to resist or rather reduce the ill-effects of piping when placed between sand and a hard compact outer covering such as concrete. When the orifice was opened under pressure, sand with water was freely blown out at first, this sand must have come from below the puddle; as soon, however, as the puddle had settled slightly the water found its way between it and the top of the tube, all *erosion* stopped and the orifice delivered clear water only.

5. The pressure gauges.—The form of gauge shown in *Plate* F was that finally adopted after trials of other patterns. Bourdon's steam or water pressure gauges are expensive and liable to get out of order when used with water carrying sand.

These mercurial gauges acted in a most satisfactory manner throughout; they were graduated directly from the standpost when the tube was filled with water only. They are subject to the fluctuations in temperature of the atmosphere, and corrections were made for large variations, but this was rarely necessary.

The stop-cock and the bracket arm of the gauge were used to get rid of air and when required to clear the orifice of the man-hole from sand.

6. Pressure lines, Khanki sand, 100 feet tube.—*Fig.* 1, *plate* C, shows the result of the first series of experiments; the tube was at this time only 100 feet long; the heads of water pressure are shown by lines on a natural scale and are remarkably regular, closely approximating to straight lines for the lower pressures, and showing a gradual increase of resistance as the head increases, until at 19 feet head the pressures are about 1½ feet above the mean line, except just close to the entrance and exit. The pressure was raised 1 foot at a time, generally at intervals of 24 hours, that is, it usually required a period of 24 hours for the maximum pressure to reach the end of the tube,

In all cases where heads of pressure were recorded, a free outlet at the end of the tube was given to the water supplied. It is evident that this is the only natural condition under which to make the experiment; if the end of the tube was hermetically closed, the level of pressure would in time become horizontal.

In 1883 I made a large series of measurements of the slope of the subsoil surface of water in the Ganges-Jumna *Doab* (*vide* Report on the Cawnpore Branch Extension of the Lower Ganges Canal); the average of the slopes measured may be taken at 1 in 250; this was of course with a free outlet at the base of the slope. The permanent slope with a free outlet of water in sand depends on the nature of the sand; it will be flat with coarse open material and abrupt with fine, or with coarse sand mixed with a large proportion of clay. In the experiment now made the tube was only 100 feet long, and therefore the limit of slope was not nearly reached; it is however, interesting to note that the regularity of slope is preserved throughout · although the outlet discharge was very small,* it might reasonably have been supposed that the heavier heads would have shown a flat slope near the head with an abrupt fall near the outlet.

It may be noted here that Khanki sand absorbs about one-third its bulk of water, and that this absorption of water appears to give it considerable stability, thus a short column of wet sand when the height=2 diameters will stand in a vertical position and support a fair weight. †

7. **Discharge of water** —The effective sectional area of sand in the tube was 2·5 square feet. The discharges measured at 10-foot intervals along the length of the tube and at the end, are given on *Plate* E; the discharges for the sake of easy reference have been shown as cubic feet per 24 hours, but in order not to interrupt the pressure experiments, they had to be measured for short intervals of time. The water that passed through this Khanki sand was perfectly colourless,‡ showing there was no admixture of clay or other very fine material

In *Fig.* 1, *Plate* E, an "S" is shown at the heads of pressure which discharged sand with the water; no further experiments could be made at or beyond these pressures as the sand was forced out in large quantities —it should be noted that the pressures given for the discharges in *Fig.* 1, *Plate* E, are those at the different intervals, not the heads in the stand-pipe.

* Varying from 1 to 10 ozs of water per minute.

† A cylinder 1¼" wide ×3" high, supported a weight of 26 ozs

‡ The water passed through the Jamrao sand had a distinct brown tinge at first.

The discharges given by these experiments are not guides to the quantity of water which will be passed under a masonry platform or through springs in a weir or regulator. There is at present no method of determining over what subsoil area the head of water, on a weir or regulator, acts. Some vague idea of this might be gained by carefully measuring the discharge under a weir under certain known conditions and applying the discharges in *Plate* E, and any other available results of a similar nature to determine the area.

8. **The effect of temperature on pressure and discharge.**—All through the series of experiments which were carried out, it was noticed that the pressures and discharges were somewhat influenced by the temperature—thus the pressures increased much more rapidly all along the tube during the day-time in the sun than at night, and the same effect was observable on a cloudy day.* It is difficult to account for this result; one suggestion made was that the increase in pressure and discharge was due to the expansion of the air entangled in the water. It was not in any way due to expansion of the mercury in the pressure gauges, since the effect was not noticed on those gauges which had reached a maximum. It was not due to air in the tube itself, as that was allowed to escape as the water was let in. It is reported by some persons that the springs from high land which feed rivers do not run so freely at night as during the day-time; this report might be enquired into.

9. **The pressure capable of blowing sand through orifices**—*See Fig.* 1, *Plate* E. On this point the experiments give fairly satisfactory evidence, and an effective pressure or head of 3 feet at any point appears capable† of blowing sand out with the water. It will be understood that with a limited area of percolation as in the experimental tube, the opening of an orifice to discharge leads at once to a reduction of pressure at that point, and in this case the sand discharge will cease after a few minutes; this would not be the case if the area of percolation was large unless the orifice also was correspondingly increased in size. Sand is carried through an orifice with water when the water discharged has to pass through an area so limited as to allow of its attaining a certain

* The same influence of temperature has been noticed in America, *vide* Bulletin No. 48, State Agricultural College, Colorado, July, 1898 It is possible that the fluidity of water increases with the temperature.

† As far as they have gone, the Jamrao sand experiments show the same result, but the quantity of water passed for each foot of pressure is greater,

velocity; if the orifice is so large that the water can pass off slowly from a large surface of sand, the sand cannot be carried in a vertical direction with the water.

In the case of cracks or springs so-called, in the floor or talus of a weir, the orifices are generally very small compared with the area feeding percolation, and consequently dangerous as regards sand draw or piping. Many persons, no doubt, have observed springs spouting sand in a weir floor some distance above a loose stone talus, and have also noticed that, although the talus was open in texture, no similar springs were observable in it. The cause of this is, no doubt, the large surface of sand open to the exit of percolated water in the talus. At the same time, it must be remembered that sand will pass away with the current from such a talus if the pressure from the head on the weir is great. Observations were made on the changes in the condition of large horizontal surfaces of sand under varying heads of pressure. It was found that the texture of the mass of sand became light and porous to a marked degree, under high heads—a heavy substance placed on the sand would sink in some distance, and the sand passed away readily with the gentlest horizontal current.

This condition of sand under pressure below a structure holding up water shows the importance of cross bars some distance below the talus. If these are slightly raised above the normal level of bed they should have an excellent effect in preventing the removal of the sand of the bed below the weir.

10. **The useful effect of curtain walls.**—*Plate* F. shows the arrangement for testing the useful effect of curtain walls below floors. When the cover plate is fixed on the open end of the box next the end of the tube, the water is forced to go below the 5-foot plate representing a curtain and to pass up through 5 feet of sand before finding an exit. *Fig.* 3.

Plate D shows the result of the only experiment made. In this case the pressure has been raised $\frac{3}{8}$ths of a foot by the 5-foot curtain; this is about equal to the rise which would be caused by a 5-feet elongation of the tube. A more complete series of experiments on this question will be made in the future.

11. **Special experiments.**—At the request of the Inspector-General of Irrigation, two experiments were made on the action of leaks of springs in floors. In the first experiment a glass pipe 4 feet high was fixed on the top of the box at the end of the tube, which was otherwise hermetically closed, and the supply of water was forced through this tube. The pressures recorded are shown in *Figs.* 1 and 2, *Plate* D.

In the second experiment the same pipe was fixed at an intermediate point in the tube, *viz.*, 75 feet from the stand-pipe end. This allowed of pressure readings being recorded both above and below the orifice—*vide Fig.* 2, *Plate* D.

In both experiments a small quantity of sand was carried up the pipes with a head of 19 feet in the first experiment and 16 to 19 feet heads in the second. The quantity of sand moved was small, but this result cannot in any way be considered conclusive, as with a larger area of percolating sand or smaller discharging orifices, the velocity of the issuing water would have been increased and more sand carried away. I am unable to devise any conclusive experiment of this nature with the existing apparatus.

12. General points of interest.—It is well to consider in what directions experiments with this apparatus are likely to be useful to the Engineer engaged in constructing works for the obstruction of water or for the Sanitary Engineer. If the tube was filled with loose gravel, the pressure slope would probably be very abrupt at the head and then flat to the tail (*see Fig.* 4, *Plate* B).

If the tube was filled with very fine material approximating to clay, the pressure slope would be the reverse of this, (*see Fig.* 5, *Plate* B), *viz.*: When the tube is filled with sands of ordinary resistance, the pressure slopes will vary as shown (*see Fig*, 6, *Plate* B), or be convex (as Khanki sand) or concave (as is likely to be the case with Jamrao sand) to the normal slope.

These results bring us to a rather perplexing point if we consider the pressure alone of springs in a weir floor at a certain distance from the head, *viz*, that the greater resistance the sands offers to the passage of water through it, the greater will be the pressure at a certain point in the floor.

This shows the great importance also of determining the pressures which are dangerous with certain materials, *viz*, those which will carry sand when exit is found as in a spring.

It would appear generally that coarse sand percolating freely requires (for stability) a shorter floor than fine sand.

It is quite clear from the experiments that a very long floor reduces loss of water-percolation.

When carrying out these experiments, it became evident that intermediate springs in a floor are great aids to the formation of long continuous cavities for currents to act along. As far as could be seen, what-

happens is that, first the very fine particles are washed out of the main body of sand along the line of least resistance; then the current increasing in force as the intervals between particles get greater owing to this washing of the material, larger particles are moved and carried away until in time the heaviest particles can be moved, and a clear channel is formed for the current of water to work in; this of course leads eventually to a subsidence of the structure or stratum above.

It is because the current takes the line of least resistance that intermediate springs are so dangerous. One near the centre of a floor will reduce its potentiality to resist piping by half.

Some experiments made with an apparatus constructed to show the action of the *mota* in irrigation wells showed very clearly the tendency of currents through sand to take the line of least resistance. It may be mentioned that where hard material exists in contact with sand, this line lies along the hard material, the same tendency of surface currents to hug spurs, rocks, and other hard edges in sandy rivers is very noticeable.* In the experiment referred to, the apparatus had a glass front, and the working of the currents could be observed clearly (*see Fig.* 7, *Plate* B).

13 Proposed section of weir.—It is impossible to form definite theories on the results of a single experiment, and all that is advanced in this note should be considered as suggestive only; the enquiry may lead to the expression of opinion from officers experienced in wet sand foundations to the great benefit of future constructors. I would however, suggest for consideration the following section as apparently that proper for a weir or other water-obstructing structure in sand.

If possible, there should also be a bar as high as the top surf ace of B some distance below the talus, (*see Fig.* 8, *Plate* B):—

If we take the water pressures on the weir section as proposed, as acting along the normal line *ho* with a head of *hp* or *lg*, it will be seen that the pressures tending to lift the weir floor B. or to force springs through it, are much less than they would be if the weir floor was given the same length *po* down-stream, as it is proposed to have above and down-stream. If all the weir floor length was down stream, the line of pressures would be *ls*.

The effective weight of the material in the structure to resist the upward pressures is only its gross weight less the weight of water displaced, and it is easy to find cases where the effective weight at a particular point

* This is due to the hard material deflecting the forces of current to directions in which they can erode the sand.

below the head is little more or even less than the pressure at that point. It will be seen that the lengthening of structure below the head actually increases the pressures at intermediate points* (*see Fig.* 9, *Plate* B.)

Now let us examine the effect of the line of pressures on the proposed section· from the diagram it will be seen that with a head of *hp* the water section contained by the triangle *hln* helps by its weight to compress the concrete and puddle on to the sand, thereby reducing percolation and adding to the stability of the structure. Moreover, an increase of head actually improves the power of the structure to resist injury, for the area of the section of water available for compression (*vide gkm*) increases more rapidly than the upward pressures.

14. *Plate* G shows the pressures on the Khanki weir due to the maximum head to date, *viz*, 5·50 feet on 16th November, 1895, and due to a presumed maximum of 10 feet. These pressures are shown plotted to a natural scale as they act on the existing weir, and also as they would act on the weir if it was protected by an up-stream apron of, say, puddle 2 feet thick covered by 1 foot of concrete, 31 feet wide in all.

This proposed apron† will be found to give a remarkable addition of stability to the weir. Examining, for instance, the point A under the four different conditions shown:—

		Net weight of weir per square foot run downward pressure.	Upward pressure of water
5·50 head weir as in 1895-96	..	240 lbs	270 lbs — 30
10 „ „ „ „	..	520 „	450 „ + 70
5·50 „ with puddle concrete	..	240 „	150 „ + 90
10 „ „ „ „	..	520 „	330 „ +190

These figures are obtained by taking the weight of weir above water level at 120 lbs. per cubic foot, and under water at 60 lbs. The 10-foot maximum head, it is assumed, will occur when nearly all the supply is removed from the river for the enlarged canal, the surface of supply has only been raised one foot.

If this is the correct method of looking at this question, it would appear that in some cases the upward pressure holding up the masonry may allow of very free sand draw, and the masonry platform will not subside until after the head has been removed. I take it that a masonry platform having all its weight resting on the sand will resist sand draw

* The grouting of the talus below a weir has the same effect.

† Captain Western, R.E., designed a similar puddle apron to protect the Jaoli Falls, Ganges Canal, in 1874, which was perfectly successful,

or piping better than a platform just suspended by the water pressure. May we not even suppose that in some instances the platform is sufficiently elastic to be very slightly lifted above the sand; in this case there would be a thin film of water admitted between the masonry and the sand which would cause a free blow-out.

As remarked before, the great advantage of the up-stream apron is that it is compressed on the sand by the excess weight of water, and there always must be an excess. Moreover, its position allows of puddle being used, and good puddle makes a most excellent joint between sand and concrete.*

15 Physical characteristics of sand.—The following statement gives the physical characteristics of three specimens of sand examined for me by Lieutenant H. Crosthwait, R.E :—

EXAMINATIOM OF SANDS—*Table of Results.*

Locality.	Angle of repose.	Specific gravity.	Percentage of insoluble matter after sulphuric acid treatment.	Percentage removed by mechanical analysis	Remarks.
Khanki ..	33° 3′	2·652	90·8	42·3	All these sands consist principally of disintegrated granite.
Jamrao ..	33° 38′	2·704	88·5	83·1	
Solani ..	39° 20′	2·640	90·9	85·4	

Explanation.

(i) *Angle of repose.*—This was obtained by measuring the inclination of the sides of a cone of sand formed by allowing the material to fall from a small height on a horizontal surface.

(ii) *Specific gravity*—Determined in the ordinary way with a specific gravity bottle.

(iii) *Insoluble matter.*—This is the percentage of insoluble silica after treatment in water chamber for 10 hours with strong sulphuric acid.

* *See* concluding portion of para. 4.

(iv) *Mechanical analysis.*—This was carried out with a view of obtaining an idea of the relative fineness of each sand by the percentage which was carried away in a given stream of water, each experiment being carried out under the same conditions The apparatus used for this purpose is shown in *Fig* 10, *Plate* B.

The sand was placed in a glass cylinder, 200 m/m high and 15 m/m in diameter. Through this cylinder an upward stream of water, under a constant head of 720 m/m, was maintained until no more sand was carried over. The remaining heavy sand was then filtered, ignited, and weighed; a comparison between this weight and that of the original quantity gives the percentage in each case which this stream of water was capable of carrying off.

Note on Experiments made on the passage of water through the sand of the Solani river at the Solani Aqueduct site, 27*th March,* 1897.

The apparatus employed was the same as that used for the experiments previously recorded on Chenab river sand at the Khanki weir site.

An examination of the sand gave the following results :—

Locality	Angle of repose	Specific gravity	Percentage of SiO_2	Precentage removed by water
Solani river . ..	39 20′	2·64	90·9	85 4

The results of this series differ somewhat from those previously reported; *Plate* I gives the record of pressures. On the gauge at 5 feet there are unexplained rises above the actual heads; these may be due to a small escape of mercury from the gauge, but no such loss could be ascertained.

The Solani sand is very fine and appears liable to blow out with lower pressures than the sands previously experimented on. In the *Plate,* S is put after the discharge when the water was milky or with little sand, and *sand* is put when the quantity was marked.

Between 10 and 11 feet pressures the head was closed for 12 days and again allowed to rise, and the effect of this is very marked. When closing off the head, the water was allowed to slowly drain off through

the tail exit, and the head was afterwards replaced to the full height at once so as to reproduce as nearly as possible the slow fall of a flood and the sudden raising of water on a weir or regulator for supply,

The *Plate* shows clearly enough that the sudden change caused injury to the tightly packed mass of sand under experiment, although none of it could possibly be displaced. I call the rise sudden, but it must be understood that it required 24 hours for the pressure to rise to the maximum throughout the 120 feet of the tube.

At 16 feet head the gauge at 95 feet was blown out and then closed; this may be compared to the formation of an open spring which, after discharging sand for some time, was closed. On raising the pressure to 17 feet and removing the curtain 5 feet deep at 120 feet, the experiment ended by the sand being blown right through the tube and freely escaping at the 120-foot exit.

It should be mentioned here that this experiment was carried out with a perfect 5-foot curtain at 120 feet, under which the tail water had to pass before finding an exit on the level of the top of the tube. The value of this curtain may be put as equivalent to 15 feet extra of weir, and there is no doubt its removal hastened to a marked extent the blowing through.

The value of a curtain at the end of a weir is marked by the way in which it prevents sand flowing slowly out with the percolation water.

Thus, if there is the slightest depression at A, *see Fig* 11. *Plate* B, the sand will flow freely along with the water, even where the velocity or quantity of the latter is very minute, while the curtain, *if perfect*, forces the current to take an upward direction, and the sand below the weir is not disturbed. I would remark that, as far as I can see, there is no object in making the curtain more than a few feet deep, but it should be perfectly water-tight. It need not be deep because the tail velocities can never be great (unless the curtain is made very deep), and it is wrong to make it deep because as each foot apparently is equivalent to adding 3 feet to the length of the weir, a deep curtain will only increase the upward pressure on the weir without adding to its strength to resist the injury caused by the falling water.

As far as the experiments have gone, I am inclined to suggest the following :—

(1) That when a large work is to be built an experiment should be conducted on the material forming the foundation, to determine the minimum width of floor which will stand the maximum head of water, *i.e.*, to determine the maximum

width which will just not stand it; this can be done by applying the head to the 120 feet of pipe and then graddually reducing the length until the sand blows through; this can be done with or without a curtain as thought best.

(II) That the width of the masonry body of the work should be 25 per cent. in excess of the theoretical minimum

(III) That the thickness of the floor should be 25 per cent. over that required to withstand the upward pressures.

(IV) That a perfect curtain should be added of moderate depth.

(V) That up-stream the work should be protected by a puddle apron (covered with concrete) of at least the same width as the floor, the joint with the floor being made with great care. This apron will materially reduce upward pressure and tendency to sand draw.

(VI) That below the floor the work be thoroughly protected with loose (not grouted) pitching, and that this stratum be constantly examined and kept up to theoretical level.

(VII) That the puddle apron be similarly protected, but here there is no objection to grouted pitching.

N. B.—The width of the masonry floor should be sufficient in all cases to withstand the mechanical action of the falling water.

It appears advantageous to provide walls dividing the length of a large work into chambers to allow of shutting off certain portions for examination or repairs.

Rapid raising or lowering of head on works appears likely to cause injury.

APPENDIX VIII.

METHOD OF CONSTRUCTION OF DAMIETTA WEIR AND LOCK.

The following very interesting account of the Method of Construction by grouting of Subaqueous Weir and Lock foundations, is extracted from the Report upon the Administration of the Public Works Department, Egypt, for 1899, by Sir W. E. Garstin, K C.M.G.

The method described appears suitable for use in many parts of India where sound foundations cannot otherwise be ensured—the main objection in India will be the heavy cost of the cement which is so largely used in this class of work.

The season's work commences, of course, by getting the plant prepared and the materials collected. As soon as the river has fallen sufficiently towards the end of November, dredging commences, and the bed of the river is taken out to the cross-section of the weir bed. As soon as the dredging is sufficiently advanced for work on the Weirs to commence, the water level is reduced to R.L. 11·50 by regulation on the Barrage. A raft, formed of two large barges kept by timbers at a convenient distance apart for forming the boxes between them, is moved into position, and a four-sided box, 9 metres long, 3 metres broad, and 8 metres high, is put together. This box is made as follows :—A double tier of horizontal frames is suspended between the barges, the lower frame being suspended by chains from the upper frame and being 4 metres below it. The upper frame is suspended at water level. The barges having been moored in correct position, the box frames are then got into accurate alignment and fixed there. The sides of the box are then formed by ungrooved sheet piles, 30 centimètres wide, fastened together in sets of five so as to form a width of 1·50 metres, and weighted at the bottom end so that they may tend to float vertically in water and be easily handled. The bottom end is shod with a piece of projecting sheet iron, so as to make a good joint with the river bed and prevent the escape of the grout. When the sides of the box have been formed, the whole interior surface of the box is lined with sacking, overlapping at the angles and at the bed junction. The sacking is kept in place and protected from being torn by the rubble, when filling is going on, by nailing thin planks about a metre apart against it from water surface to bed. Divers are constantly at work

during these operations. Four perforated pipes ar then fixed along the axis of the box at equal distances, and the box is filled with rubble and concrete metal (20 per cent.), and pebbles (15 per cent) thrown in from above, up to slightly above water level. Unperforated pipes are then inserted into two alternate perforated pipes, reaching nearly to the bottom of the box · on the top end of these pipes are screwed funnels, and over the funnels are fixed coarse wire sieves to catch the pieces of paper of the cement barrels and other foreign substances that may get mixed with the cement grout. In the other two pipes floats, which sink in water and float in cement grout, are suspended, so that the rise of the grout may be watched. The object of grouting into an unperforated inner pipe is to deliver an unbroken column of grout at first at the bottom of the box, and afterwards just below the surface of the sea of ascending grout. If grout were poured directly into the perforated pipe, each bucket of grout would have to fall through water. The inner pipes are changed over from time to time to the alternate perforated pipes, and gradually shortened as the grout rises higher. To lessen the danger of leaks at the bottom of the box from the pressure of too great a head of liquid grout (which being twice as heavy as water exercises a pressure in water equal to the pressure exerted by a head of water in air), it was generally arranged that a depth of one metre should be grouted over night, and be left till the next morning to set, so as to form a solid bottom to the box on which the rest of the grout would be supported.

The grouting was continued next day until the grout rose slightly above the water surface : the scum was cleared away, and stones put by hand into all the spaces where there was an excess of cement grout. The block was then left for the night, and next morning was found to have set hard enough for the box, in which it was formed, to be loosened and moved forward.

The second and subsequent boxes were made as three-sided boxes, the last grouted block forming the fourth side, and being clasped by the side beams of the horizontal frames.

A box and its contained block took from three to four days to make, so that, when the four rafts were at work, the average rate of progress was about 10 metres of core-wall or lock-wall a day. Each block contained from 160 to 170 cubic metres of masonry and was about 9 metres long by 3 broad and 6 high At the commencement of the season, the blocks were 7½ metres high, decreasing to 6 metres as the water fell.

The cement grout was mixed by hand in iron troughs by ordinary labourers, gangs of Soudanese Blacks being the best mixers. The consistency of the grout varied from thin to thick, the proportion of water depending on the judgment of the mixers. When first using cement grout to strengthen the Barrage foundations, attempts were made to measure the amount of water, but, in consequence of the peculiar nature of the workmen, the measuring was never properly done, and so it was decided to give up the measures and to control the consistency by observing what was brought in buckets to the grouting pipes. Experiments and experience on the work itself seemed to show that, whether thin or thick, the cement grout set satisfactorily and gave the desired result. Possibly the grout, in consequence of its high specific gravity, gets rid of excess of water when it is in a liquid mass and free to do so. Whatever the explanation, it appeared to be unnecessary to be particular about the proportion of water in the grout when used as in the work under description. But it is necessary to be careful to get a cement that will behave satisfactorily under such severe conditions, and this appears from experiments made with many kinds of cement not to be a difficulty.

The lock foundations were got in entirely by grouting, and, as I believe this system has never been applied to such an operation before, it may be useful to describe the manner of doing it (*see Plate* J).

The foundation bed was dredged out all over to R.L. 5·50, and the water level reduced by regulation on the Barrage to R.L. 10 00. Two parallel walls, bounding all the lock area on either side were then formed by the same system as that adopted for the formation of the core-wall. The rectangle of which these walls formed the sides (100 metres long by 17 metres broad between the walls) was then closed at the two ends by sheet piles supported by horizontal beams, which were kept in place by piles driven a short distance into the bed of the river and tied at their tops to the side walls already formed. A staging was then constructed across the enclosed space from side wall to side wall, and the perforated pipes fixed in place about 3½ metres apart all over the area. Two metres depth of rubble, concrete metal and pebbles were then thrown in to form the floor foundation. At about one metre distance from the two ends a second interior cross wall of sheet piling was arranged with the lower ends below the level to which the two-metre layer of rubble would come. All the sheet piling was lined on the inside with sacking to prevent the escape of cement grout between the joints, in the same way as in the boxes.

When the two-metre depth of floor material had been deposited, grouting commenced at one end of the lock and continued day and night till the other end was reached. The grouting commenced on the 19th May at 7 a.m., and finished at midnight of the 22nd. The end walls were then filled and grouted. On the 26th April the enclosed space was pumped out in half a day, and the grouting was found to have formed a perfect floor without the sign of a spring in it. The rest of the lock floor and walls was built in the dry in the ordinary manner.

As the grouting was executed under water and was not continued, as in the boxes, until the grout rose above water surface, arrangements had to be made for ascertaining to what level the grout had risen. A simple arrangement revealed this. The grout was poured into alternate pipes, and in the pipes, where grouting was not going on, a float was suspended so weighted that it would sink in water and float in cement grout, the specific gravity of the latter being double that of the former. The string to which the float was attached was passed over a pulley wheel, and the other end of the string weighted sufficiently to keep the string taut.

By this method a perfect sound floor is obtained, as no troublesome springs create defects by forming a way under or through the masonry while under construction. When the cement has set, the springs are all effectually shut out and helpless, and the enclosed water can be pumped out without any fear or difficulty.

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